NASA Conference Publication 2066

Ozone Contamination in Aircraft Cabins

A workshop held at
Ames Research Center
Moffett Field, California
July 27-28, 1978

NASA

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A workshop sponsored by
NASA Office of Aeronautics
and Space Technology
Washington, D.C., and held
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Moffett Field, California
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FOREWORD

A 1 1/2-day workshop was held at the NASA Ames Research Center, Moffett Field, California, to assess the present state of coping with the problem of physical ozone irritation caused by ozone concentrations in the cabin of high-altitude aircraft and to recommend areas of R&D effort which would provide viable solutions to this problem. The workshop participants represented airline and airframe companies, equipment manufacturers, university and company research organizations, cabin crews, and government agencies (FAA and NASA). All active attendees were participants in one of three panels established to discuss the concentration levels of ozone currently being observed in aircraft cabins and methods to reduce or eliminate these concentrations.

This publication summarizes the findings and recommendations of the three working groups. Visual aids used for the overview papers are also included.

Theordore Wydeven, Jr.
NASA Ames Research Center
Cochairman

Porter J. Perkins
NASA Lewis Research Center
Chairman

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INTRODUCTION

Porter J. Perkins
NASA Lewis Research Center

High concentrations of ozone that have been measured in the cabins of some jet aircraft by NASA and others are of concern to both flight crews and passengers as well as industry and government organizations. The FAA, aircraft manufacturers, and airlines have been working on the problem in several ways. Among these ongoing efforts is the issuance of an Advance Notice of Proposed Rule Making (ANPRM) by FAA to elicit advice on problem solutions and the installation of charcoal filtering equipment by manufacturers to reduce ozone concentrations in the cabin of one aircraft type.

NASA became involved in the cabin ozone situation coincidentally when complaints of physical discomfort occurred during flights of airliners equipped with the NASA GASP (Global Air Sampling Program) system. This system measures ambient levels of air constituents in the upper atmosphere (including ozone) which are related to jet engine exhaust emissions NASA measurements of high levels of ambient atmospheric ozone correlated with the complaints from aircraft occupants. Even though the GASP system was installed for atmospheric research purposes, it was nonetheless instrumental in identifying the presence of high levels of atmospheric ozone at times when discomfort was reported by passengers and crews. An extension of the GASP equipment was made on two GASP equipped B747 aircraft to permit simultaneous measurements of internal aircraft ozone at one point in the cabin and of ambient atmospheric ozone.

As a result of this involvement, NASA and FAA have been discussing how NASA capabilities may be utilized in providing solutions to the problem. As a first step in structuring a program to provide appropriate assistance to the air carrier industry, an assessment of the current understanding, state-of-the-art, and specific areas needing research, if any, appeared fitting at this time. Since such an assessment would properly involve specialist groups of widely divergent backgrounds, an Ozone Specalists Workshop was organized to accomplish these objectives.

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REMARKS

John H. Enders
NASA Headquarters

On behalf of my NASA colleagues, welcome to this specialists Workshop on ozone. The background events leading up to this meeting were described briefly in our invitation letter to you.

You participants have a broad diversity in skills and backgrounds, yet a common interest in the ozone problem as it affects aircraft flight comfort and safety. Much as in the fable of the blind men describing the elephant according to the respective areas each felt, we each have a different view of the ozone problem. Our aim today and tomorrow is to describe the entire ozone elephant with the exception of health physics aspects. That appears to be a matter for the medical community to deal with, although for background purposes, Dr. Carl Melton of FAA's Civil Aeromedical Institute will provide a brief overview of ozone toxicity. We will attempt, with the existing and contemplated ozone exposure standards of OSHA, EPA, and FAA, to examine the engineering problems associated with meeting those standards.

You workshop registrants represent the professional fields of flight and cabin crew; airline engineering, operations, and meteorology; aircraft and equipment manufacturers, university and other private research institutions; government researchers; and government regulators. Mr. Perkins will describe the working details of three interactive groups where you each will have ample opportunity to describe your view of the problem, argue with your colleagues, and attempt to reach a concensus regarding R&D needs, data base needs, regulatory needs, promising approaches to design, and so on. NASA will use the outputs of this Workshop to assess the needs of the technical and operating community which can be served by R&D and to examine how our particular expertise and capability may be applied to the R&D needs.

The overview presentations and the working group reports will be published in a Workshop Proceedings within a few weeks. Each of you will automatically receive a copy, and additional copies will be available through the National Technical Information Service.

In closing, I express our pleasure at this evidence of interest in the ozone topic, and wish each of you a highly productive Workshop.

OBJECTIVES AND APPROACH

Porter J. Perkins
NASA Lewis Research Center

The basic objectives of the Ozone Specialists Workshop were to determine present means of coping with the problem of ozone contamination in aircraft cabins and to identify R&D efforts needed to provide solutions. The approach used to pursue these objectives was to form three topical panels. One panel concentrated on obtaining a better definition of the problem. Two other panels assessed solutions.

A thorough definition of the problem can best be derived from direct in-flight measurements of ozone concentrations inside and outside airliners in their normal operations. The panel set up to look into this area was identified as the Panel on In-flight Measurements. Ambient or outside ozone measurements would contribute to establishing the characteristics of ozone concentrations as encountered by airline aircraft. Additional simultaneous measurements of ozone inside the aircraft would determine the normal attenuation of ambient ozone by cabin air systems in different types of aircraft.

Ozone encounter characteristics include the ozone concentrations, variability, duration, frequency, and relation to season, latitude, and synoptic meteorology. Attenuation of ozone by cabin air systems has been determined by NASA on the B 747-100, B 747-SP, and the Gates Learjet. On the two types of B 747's where measurements were made, a large variability of ozone losses in the cabin air were found. This would infer that other types of aircraft would be different and need to be determined to clearly identify the problem for the many different types of aircraft in the airline fleet.

Solutions to the cabin ozone problem were discussed under two areas: (1) flight planning to avoid high ozone concentrations, and (2) ozone destruction techniques installed in the cabin air systems. The two panels were organized under these titles. Flight planning may be an interim procedure until ozone destruction hardware can be made operational, or as an established procedure used on air routes where excessive ozone may be only a rarity. Flight planning will need to have basic guidelines as well as a better understanding of ozone concentration and corresponding meteorological data along air routes for preflight forecasting. Flight planning could also include possible establishment of in-flight procedures if high ozone is encountered. Ozone destruction techniques are a direct solution. Considerations must be given to size, weight, cost, and maintainability. Optimum designs need an understanding of the basic technology for the mechanism of destroying ozone. Since ozone can be destroyed by several means, screening tests on materials and processes to determine effectiveness, life, and possible configurations would be appropriate. A good candidate technique would require a representative aircraft installation and subsequent flight demonstration to prove performance.

The results of the Workshop are in the form of recommendations for research and development effort to better define and solve the cabin ozone problem. The Workshop also provided an up-to-date assessment of the problem presented in several overview papers. The recommendations and assessment will help guide NASA and others in determining how their capabilities may be applied in reaching satisfactory solutions to the overall problem.

RECOMMENDATIONS OF THE PANELS

Panel on In-Flight Measurements

Jim Rogers
Federal Aviation Administration

The panel on in-flight measurements reviewed the past and current NASA measurement program with regard to data utilization and investigated possible future measurement needs in which NASA's expertise would be utilized. The purpose of future measurements would be similar to that for the current NASA program and data would be obtained in the following areas: aircraft attenuation of ozone levels from ambient to cabin, evaluation of aircraft ozone "fixes", ambient ozone levels for data base statistics and correlation factors between ozone levels and complaints. Data could be obtained by a modified continuation of the current NASA Global Air Sampling Program (GASP) with limited measurements extended to other aircraft types.

The specific panel recommendations are the following:

1. A definite need exists to obtain the attenuation factor for aircraft other than the B-747 in reducing the ambient ozone concentrations which enter the cabin. This data is required by engineers in designing optimum ozone removal equipment for individual aircraft. A compact version of the GASP instrumentation package with outside air obtained through a pitot tube would have to be developed to obtain this data. Relatively few flights, preferably during high ambient ozone concentrations, would be necessary to obtain the attenuation factor for any one aircraft type. It is desirable to obtain these data during the next ozone season with initial measurements on the following aircraft; DC-10, L-1011 (and L-1011-500 when operational), DC-8 (standard and stretched), A-300 and B727. Possible additional measurements may be required on other commerical aircraft and on some high performance general aviation aircraft.

2. A need to continue "GASP type" measurements was expressed for three main purposes; testing new filters, correlation of complaints with ozone levels, and ambient ozone data. The need in the first two areas in self-evident. Additional ambient ozone statistical data has been stated as a need by groups investigating flight planning to avoid high ozone concentrations and those designing ozone reduction devices. Of the three airplanes presently flying as part of GASP (with program termination scheduled at the end of February, 1979), the first priority is to continue the Pan American (PA) B-747SP (#533) data acquisition. This data is needed to satisfy requirements in all three areas. Present plans by industry are to have a catalytic filter installed in this aircraft for testing during the next ozone season. These plans include NASA ambient and cabin ozone data as an integral part of the test procedure. Continued measurements would also provide information for complaint correlation and ozone statistics. The secondary priority is to continue data acquisition on the other two GASP airplanes. The United Airlines (UA) B-747-100 (#4711) measures both ambient and cabin ozone levels and the data would provide complaint correlation information and ozone statistics. The PA B-747-100 (#655) would only contribute to the ozone statistics as ambient ozone levels alone are measured.

3. The panel indicated a need to continue cooperation between NASA and industry. Specifically, transfer of ozone measurement technology, including instrumentation and operation, is desirable.

4. Since NASA's measurements indicate that the ozone attenuation factor is highly sensitive to the cabin loading in small-volume general aviation aircraft, it is desirable to determine the extent to which commercial aircraft cabin load factors influence the attenuation. Load factors on past GASP flights would be difficult to obtain, but consistency of the attenuation factor on the non-filtered UA B-747-100 should indicate if this is important.

5. Concern was expressed with regard to the correlation of ozone levels and complaints. Two carriers represented on the panel have had negligible success in obtaining consistent correlation. It is suggested that a correlation between ozone levels and reported complaints be attempted for all GASP data flights. This concern raises the possibility that all complaints are not ozone related and measurements other than ozone may be required in the future. For the present, it was recommended that the GASP water vapor instrument should be used to measure the relative humidity in the cabin of the PA B-747SP.

6. The need to measure the variability of ozone within the aircraft cabin was investigated. While there were some reports of the ozone level being variable, both Pan American and United Airlines have used their own portable ozone monitors on the GASP airplanes and feel that the single GASP ozone acquisition point is representative of their measurements. The consensus is that no NASA involvement in measuring the ozone variability in the cabin is required at this time. If measurements are needed in the future, they can be obtained by portable ozone monitors.

7. The last item discussed was the requirement for an onboard ozone monitor on all aircraft. It was felt that interpretation of the data from such a monitor for use in ozone avoidance is uncertain at this time. At present, no NASA involvement in this area is seen as the requirements are not known. If a requirement would arise in the future, the instrument manufacturers were considered capable of satisfying developmental needs.

Volker Mohnen
State University of New York at Albany

THE PROBLEM

Climatological data available at this time strongly indicates that a large majority of flights today are accomplished at latitudes, altitudes, and seasons such that ozone exposure is not a problem. The panel has therefore limited its recommendations to those flights planned or accomplished during certain months of the year at the higher latitudes and altitudes at or above the tropopause.

PRESENT CAPABILITY AND IMPROVEMENT NEEDED

The panel recognizes that presently available data are sufficient to qualitatively define areas of high and negligible risk of exposure to potentially hazardous amounts of ozone. If cabin ozone level limitations are established, additional information is required for more accurate and quantitative forecasting and design data base for operational utilization. The following information and parameters are needed:

A. Better tropopause heights. Reported tropopause heights as analyzed and transmitted by NMC are too inaccurate for quantitative ozone forecasts. A better definition of forecast tropopause height and type is needed.

B. Ozone concentration and corresponding meteorological data along selected flight routes. The Global Atmospheric Sampling Program (GASP) at NASA Lewis has established a unique measurement program along major flight routes which has proven invaluable for initially defining the cabin ozone problem. It is essential that these measurements be continued and expanded to cover such critical areas as polar flight routes.

C. Meteorological data

1. NMC hemispheric meteorological data at all available levels including vertical motion fields in the stratosphere.

2. Tropopause heights and types.

3. Satellite total ozone data.

OPERATIONAL OZONE FORECASTS

Using the above data, NASA should support the development of an operational ozone forecast model by a group of specialists. The panel feels that any future operational forecast should be provided by the National Weather Service.

It is noted that most of the basic ozone and meteorological information, adequate for a preliminary study, is already available at some active centers. Additionally, total ozone satellite data may be available on an operational basis in the near future. Models must be developed, however, to relate these data to quantitative ozone forecasts at flight levels. These forecasts will depend heavily on a more precise definition of tropopause heights than is now given.

VERIFICATION OF OZONE FORECAST MODELS

Forecast models must be validated on a frequent basis. The panel recognizes that the GASP data should be the primary data base for that purpose. Supplementary aircraft measurements are highly desirable.

UNITS STANDARDIZATION

The airline members on the panel suggest that a consistent set of units be used for ozone measurements. Regulations are generally stated in parts per million, but airline operational personnel prefer parts per billion. Medical effects on the body are a function of mass concentration rather than number concentration. This matter was not resolved.

Panel on Ozone Destruction Techniques

Ted Wydeven
NASA Ames Research Center

The panel on Ozone Destruction Techniques discussed three general areas:

1. Ozone scrubber design,
2. Adsorbent or catalyst selection and characterization,
3. Alternate approaches to ozone removal.

In panel discussions on the second day of the Workshop items 1 and 3 from the list of three items were eliminated. "Ozone scrubber design" was eliminated because it was generally thought that airframe manufacturers could do a better job than NASA in the engineering of scrubbers for aircraft. "Alternate approaches to ozone removal" was eliminated from further consideration because none of the alternate approaches that have either been tried or thought of appeared to solve the problem of cabin ozone. Alternate approaches were either totally ineffective or only partially effective. In some cases alternate approaches were also too inefficient and costly.

The one area in which the panel felt NASA could make significant contribution was in the development and characterization of new materials for ozone removal. The primary objective in developing new materials for for ozone destruction would be to reduce weight, size and cost of the ozone removal device. The projected weight of the ozone scrubber using currently available catalyst materials is 150 pounds. No cost or size figures were given for currently available materials. In the development of new catalyst materials, it was thought desirable to seek catalysts that were effective in the two different temperature regimes: 1). 200-600^{o}F 2). ambient to 250^{o}F temperature. Different aircraft would require catalysts that operate in these different temperature regions.

In addition to developing improved materials for ozone destruction it was generally thought by our panel members that NASA could contribute in the following areas:

1. Study catalyst bed lifetime,
2. Study competitive reactivity (i.e., the influence of other contaminants in the inlet air on the catalyst bed efficiency for ozone removal,
3. Study the kinetics and mechanism by which ozone is destroyed on selected catalysts.

The reasons for studying 1 and 2 are obvious while the reasons for studying 3 are not immediately apparent. The panel thought NASA should study the kinetics and mechanism of ozone destruction for two reasons: 1) with this data available one could predict how the catalyst should perform under conditions not tested in the laboratory, 2) knowing the mechanism of ozone destruction on a given catalyst may aid in specifying the requirements for new and improved catalysts.

Catalyst evaluation conditions would be:

1). Contact or residence time - 5 to 60 milliseconds

2). Inlet ozone concentration 1.5 ppm
Outlet ozone concentration - 0.1 ppm

3). Operating pressure - 30 - 35 psig (same as 8th stage of compressor).

SUMMARY OF RECOMMENDATIONS

Porter J. Perkins
NASA Lewis Research Center

The major recommendations submitted by the three Workshop Panels are summarized as follows:

Panel on In-Flight Measurements recommended:

1. Determination of the attenuation of ambient ozone in the cabin air systems for several different types of aircraft to further define the overall problem. (Required by design engineers)
2. Evaluation of new ozone destruction devices during airline operations.
3. The health complaints compilation submitted at Workshop by representatives of the flight attendants be assembed with measured ozone levels where available during a given flight.
4. Statistical data on ambient ozone be provided for flight planning and design engineers.
5. Determination of the dependency of ambient ozone attenuation on cabin load factors.
6. Relative humidity in the cabin be measured using the GASP water vapor instrument.

Panel on Flight Planning to Avoid High Ozone recommended:

1. Measured ozone concentrations be correlated with regularly acquired meteorological variables to refine present ozone forecast techniques.
2. For more accurate and quantitative ozone forecasting, meteorologists need:
    a. Better tropopause height reports.
    b. Understanding of relationship between high ozone and corresponding measured meteorological variables.
    c. NMC hemispheric meteorological data at all available levels including vertical motion fields in the stratosphere.
    d. Satellite total ozone data.

3. Development and verification of an operational ozone model. (The Panel noted that these recommendations would be limited to flights during certain months of the year at higher latitudes and at altitudes at or above the tropopause. Available data indicate that a large majority of lights are at latitudes, altitudes, and seasons where ozone exposure is a negligible risk.)

Panel on Ozone Destruction Techniques recommended:

1. Development and characterization of new and improved materials to reduce weight, size, and cost of ozone removal devices.
2. Study of catalyst bed lifetime.
3. Study of influence of contamination on catalyst bed efficiency.
4. Study of kinetics and mechanisms by which ozone is destroyed on selected catalysts.

POST WORKSHOP REVIEW OF RECOMMENDATIONS

Porter J. Perkins
NASA Lewis Research Center

The three Panel Chairmen, the Workshop co-chairman, and representatives from FAA met with Mr. Jack Enders on September 15, 1978, in Washington D.C., to review the recommendations of the Workshop and to explore ways of implementing them. Also a level of priority was established for their accomplishment. Suggested responsibility for implementation was mainly given to NASA, although the group felt that the recommendations in the area of ozone meteorology and forecasting could be better accomplished by NOAA.

The following chart lists the recommendations, level of priority for accomplishment, and recommended approaches and responsibility for implementation as established by the review group.

OZONE SPECIALISTS WORKSHOP

Post Review of Recommendations

RECOMMENDATIONS	RECOMMENDED IMPLEMENTATION
1. Determine attenuation of atm. ozone in cabin air systems for DC-10, L-1011, DC-8's, B-727, A-300. (A)	A new data acquisition effort. Use GASP equipment, maintenance facilities, data processing capability. *NASA
2. Evaluate new ozone destruction systems during airline operations. (A)	Continue GASP ozone data on instrumented 747-SP and other aircraft. *NASA
3. Assemble measured ozone levels with health complaints. (A)	Use available GASP data from 747 - 100 & SP. *FAA
4. Need new and improved materials to reduce weight, size, and cost of ozone removal devices. (A)	Develop and characterize new materials obtained from catalyst manufactures. *NASA
5. Study catalyst bed lifetime. (A)	Laboratory effort. Validation by industry. *NASA
6. Study influence of contaminates on catalyst bed efficiency. (A)	Laboratory effort. *NASA

POST REVIEW OF RECOMMENDATIONS (CONT.)

RECOMMENDATIONS	RECOMMENDED IMPLEMENTATION
7. STUDY KINETICS AND MECHANISM BY WHICH OZONE IS DESTROYED ON SELECTED CATALYSTS. (B)	LABORATORY EFFORT. *NASA
8. COLLECTION AND ANALYSIS OF OZONE DATA FROM CRITICAL GEOGRAPHICAL AREAS SUCH AS POLAR FLIGHT ROUTES (C)	AVAILABLE FROM SOME EXISTING DATA. CONTINUE GASP DATA ANALYSIS PROGRAMS. *NASA
9. CORRELATE OZONE CONCENTRATIONS WITH AVAILABLE MET. DATA TO REFINE OZONE FORECAST TECHNIQUES. (C)	NEW ANALYSIS EFFORT. USE NMC & NWS TRANSMITTED DATA WITH GASP OZONE DATA DURING COMING SEASON. * NASA & NOAA
10. FOR MORE ACCURATE AND QUANTITATIVE OZONE FORECASTING METEOROLOGISTS NEED: (C)	ESTABLISH TRAIL PROGRAM WITH AIRLINE MET. OFFICES AND EVALUATE WITH GASP DATA. *NOAA
A. BETTER DEFINITION OF FORECAST TROPOPAUSE HEIGHT AND TYPE.	RESEARCH EFFORT. *NOAA
B. UNDERSTANDING OF RELATIONSHIP BETWEEN HIGH OZONE CONCENTRATIONS AND CORRESPONDING MEASURED MET. VARIABLES	AN ONGOING PROGRAM. *FAA

POST REVIEW OF RECOMMENDATIONS (CONT.)

RECOMMENDATIONS	RECOMMENDED IMPLEMENTATION
C. NMC HEMISPHERIC MET. DATA AT ALL AVAILABLE LEVELS INCLUDING VERTICAL MOTION FIELDS IN STRATOSPHERE.	RESEARCH EFFORT. *NOAA
D. SATELLITE TOTAL OZONE DATA.	AVAILABILITY ON OPERATIONAL BASIS IN NEAR FUTURE IS QUESTIONABLE.
11. DEVELOP AND VERIFY AN OPERATIONAL OZONE FORECAST MODEL. (C)	BY GROUP OF SPECIALISTS UNDER DIRECTION OF NOAA
12. DETERMINE DEPENDENCY OF ATM. OZONE ATTENUATION ON CABIN LOAD FACTORS. (C)	USE GASP DATA FROM 747-100 & SP. *NASA

( ) PRIORITY LEVEL

* SUGGESTED RESPONSIBILITY

APPENDIX A - OZONE TOXICITY

Carlton E. Melton
FAA Civil Aeromedical Institute

Christian Friedrich Schonbein, in 1847, first noted the presence of an odorous gas near electric generators. He found that the gas had toxic effects on himself and experimental animals, and named the gas "ozone" after the Greek word meaning "to smell." Over 130 years later we are still trying to determine what ozone does to living systems and how it does it.

Much of what we know about the long-term effects of ozone on human health comes from the effects of ozone formed in photochemical smog. We assume that the effects of photochemical smog, a mixture of oxidants, are the same as the effects of natural ozone in the stratosphere. Much evidence is also available from laboratory experiments on humans and animals, most of which relate to the acute effects of ozone.

There is no doubt that ozone is extremely toxic. About 0.018 ounces of ozone in a 55 gal drum of air (ca. 0.40 parts per million by volume (ppmv)) would be enough to cause symptoms in some people. These symptoms would be nasal dryness, cough, pain beneath the breastbone, perhaps headache, and a burning sensation in the throat. Some people may also complain of eye irritation.

How does ozone produce these symptoms? Current concepts tell us that we must look at the molecular biology involved in order to have some understanding of ozone's effect. Molecules are made up of aggregates of atomic nuclei surrounded by orbiting electrons. These electrons exist in orbital pairs, with the members of each pair spinning in opposite directions. This opposite spin condition produces strong coupling between the electrons. When all orbitals have their full complements of electrons, the molecule is stable. When an electron acceptor takes away an electron, the electrons are uncoupled and a reactive free radical is formed. Living systems are characterized by free radical formation with an orderly electronic flow from acceptor to acceptor until finally the electrons are passed to oxygen.

When ozone (O_3) breaks down in water, as in the body, it forms a hydroxyl (OH.) free radical. This is a powerful electron acceptor and makes other free radicals of electron donors. These are aberrant free radicals and do not fit the normal orderly flow of cellular energy. Their disruptive effect produces metabolic disturbance that is reflected in altered cell function. If enough cells are affected, the symptoms of ozone toxicity with which we are familiar appear. In this regard, the effects of ozone resemble the effect of ionizing radiation which also produces free radicals. Radiation is much more effective because of its deeper penetration and widespread route of entry into the body.

How much ozone will cause enough damage to produce symptoms? The published literature tells us that normal people are generally not affected by less than 0.30 ppmv. At a concentration of approximately 0.30 ppmv effects measurable in the laboratory begin to appear. Between 0.30 and

0.50 ppmv reversible symptoms noticeable by the affected person begin to appear. Above 0.50 ppmv damage begins to appear that outlasts the period of exposure. Above 1.0 ppmv serious damage begins to occur with stupefaction reported to occur at about 5.0 ppmv. Thus, the critical dividing line between serious and mild effects is about the 0.50 ppmv level.

We can list several things regarding ozone toxicity for humans gleaned from the literature. (1) For normal people, the biological threshold for ozone effects (aside from odor) probably lies between 0.20 and 0.30 ppmv; (2) Effects are probably first detectable in blood; (3) Symptoms noticeable by the affected person appear between 0.30 and 0.50 ppmv; (4) Some people are more reactive to ozone than others. Asthmatics and people with allergies commonly react at lower levels of exposure than others, young people seem to be more sensitive than old people and smokers are less sensitive than nonsmokers; (5) It is commonly stated that ozone is an eye irritant. The consensus from the literature is that it is not; (6) Visual effects have been demonstrated in only one set of experiments; (7) Adaptation to ozone occurs but the mechanism is obscure; (8) Extrapulmonary effects (other than in blood) may occur but the mechanism is unknown; (9) The long-term effects of ozone on humans are not well defined; (10) Effects of ozone are more dependent on concentration than on duration of exposure; (11) Good evidence exists that free radical scavengers, such as vitamin E, mitigate the effects of ozone. Not much experimentation has been done on humans in this regard; (12) Ionizing radiation, high pressure oxygen, hydrogen peroxide, and ozone probably have similar basic toxic actions;

and (13) No report of human death from ozone exposure has been found in the literature.

Finally, it would facilitate comparisons of studies of the biological effects of ozone if exposure levels were expressed in terms of mass per unit volume instead of volume per volume. The reason for this recommendation is that at various altitudes the amount of air with which ozone is mixed changes, thus changing the volume per volume relationship. Expression of ozone levels as mass per volume (mg or μg per cubic meter) truly expresses the biological dose regardless of the altitude and requires no correction

APPENDIX B - OVERVIEW PAPERS

In-Flight Measurements

Porter J. Perkins
NASA Lewis Research Center

There are two sources of in-flight ozone measurements; they are the NASA Globlal Atmospheric Sampling Program (GASP) and the carry-on ozone monitors used by other organizations. GASP consists of continuous daily measurements of ambient data since March 1975 and in-cabin data since March 1977. The in-cabin data are taken at one location in the cabins of a 747-100 and a 747SP. This program is scheduled to terminate in June 1979. The carry-on ozone monitors used by the FAA, the airlines, and other organizations measure ozone at several locations in the cabin. Only GASP data are presented here.

The objectives of the GASP ozone measurements are to establish the characteristics of ambient (outside) ozone concentrations during routine operations, and to determine the attenuation of ambient concentrations of cabin air systems from simultaneous ambient and in-cabin measurements. Characteristics of ambient ozone include:

(1) Maximum concentrations
(2) Duration of ozone encounters
(3) Frequency of ozone encounters
(4) Variability of ozone during a flight
(5) The above characteristics in relation to routes, altitude, and metorological conditions.

Ozone is measured at only one point in the cabin (fig. 1).

Ambient or atmospheric ozone concentrations can on some occasions vary widely along the flight path of a high altitude commercial airliner, ranging from less than 100 parts per billion by volume (ppbv) to over 1200 ppbv (fig. 2). Large and rapid (within 5 min) excursions of ozone concentrations can occur during high ozone encounters.

Simultaneous measurements of atmospheric and in-cabin ozone reveal an average attenuation factor of 62 percent (retention of ozone in the cabin of 38 percent of the atmospheric concentration) for the B747-100 airliner (figs. 3 and 4 and table I). However, the B747-SP type airliner showed a retention in the cabin averaging 80 percent of the atmospheric ozone (fig. 5 and table I). This was reduced to 5 percent on this aircraft when charcoal filters were installed in the cabin air system to destroy ozone (fig. 6 and table I).

Similar ozone measurements in a Gates Learjet Business jet conducted by NASA showed ozone retention in the cabin to range from 41 to 75 percent depending upon the load in the cabin (fig. 7 and table II).

Atmospheric ozone measurements from GASP-equipped airliners can establish the susceptibility of these aircraft on their specific route structures to high cabin ozone concentrations. A full year of data from the B747-100 airliner disclosed that, statistically, ozone concentrations are highest in the second quarter and peak during April (figs. 8 to 10).

TABLE I. - CORRELATIONS BETWEEN ATMOSPHERIC OZONE CONCENTRATIONS AND IN-CABIN OZONE LEVELS FOR B 747 AIRLINERS (SELECTIVE SAMPLE FLIGHTS WITH AND WITHOUT OZONE DESTRUCTION TECHNIQUES USED IN CABIN AIR SYSTEM)

Aircraft type	Added technique for reducing ozone	Ozone retention in cabin, percent of atmospheric level
B-747-100	None	38
B-747-SP	None	80
	Modified cabin air circulation	58
	15th-stage compressor bleed	19
	Charcoal filter	5

TABLE II. - CORRELATIONS BETWEEN ATMOSPHERIC OZONE CONCENTRATIONS AND IN-CABIN OZONE LEVELS FOR GATES LEARJET

Flight	Aircraft cabin configuration	Ozone retention in cabin, percent of atmospheric level
1	Relatively empty	75
2	↓	65
3	↓	61
4	↓	52
	Average	63
5	Relatively full	43
6	Relatively full	41
	Average	42

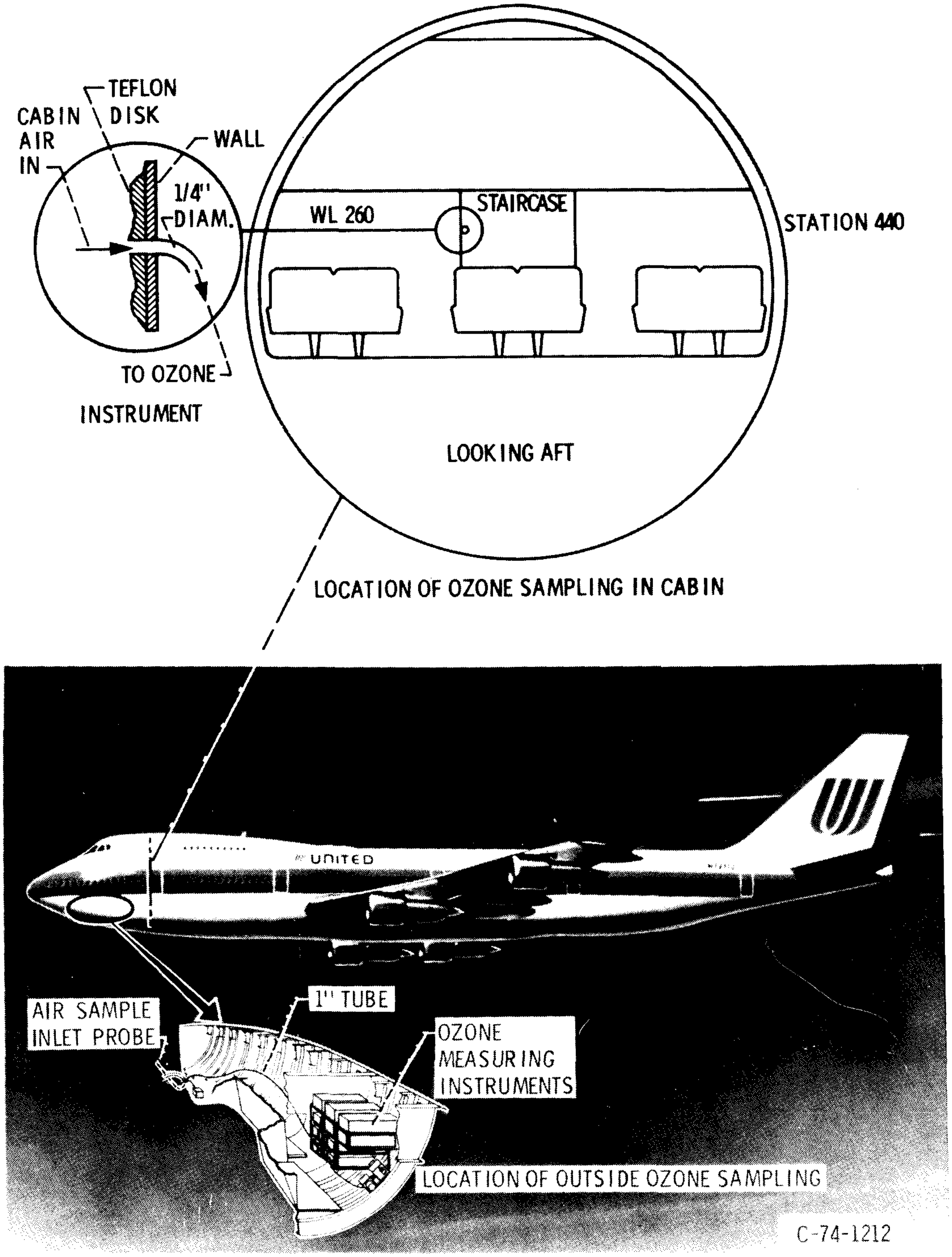

Figure 1. - Ozone measurement locations on B747 airliner.

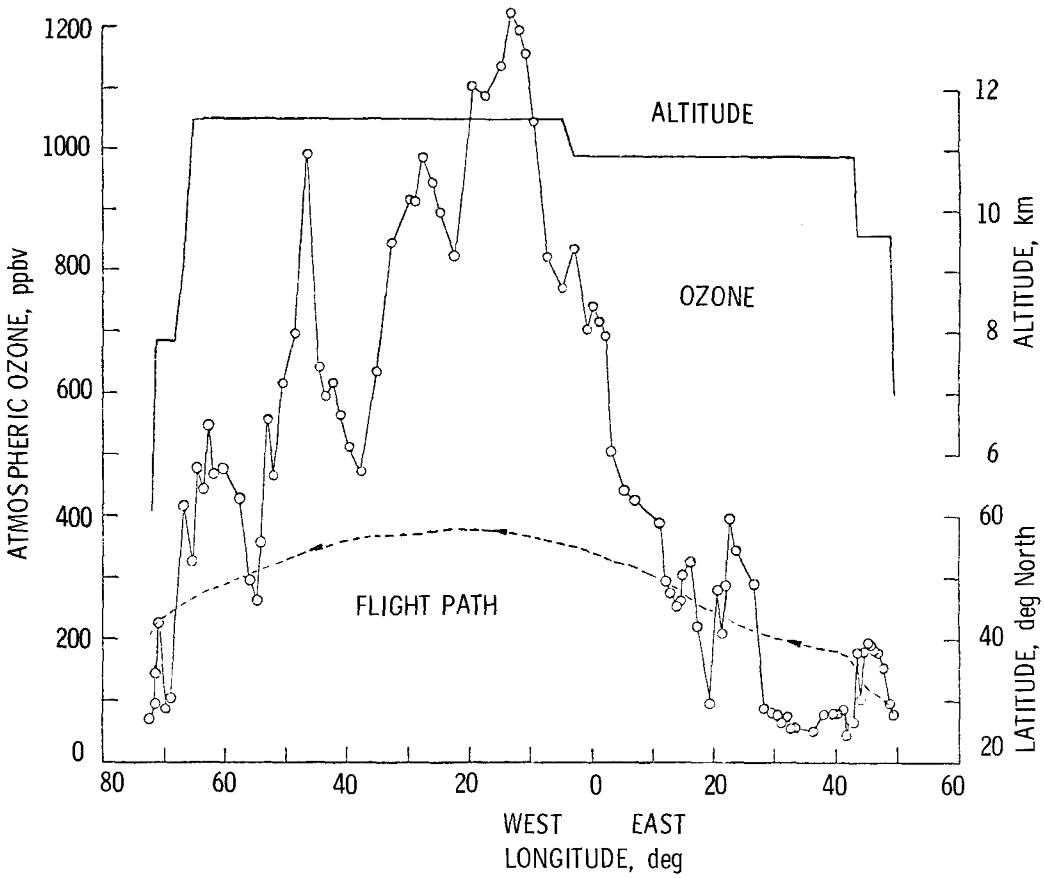

Figure 2. - Example of a high ozone concentration encounter.

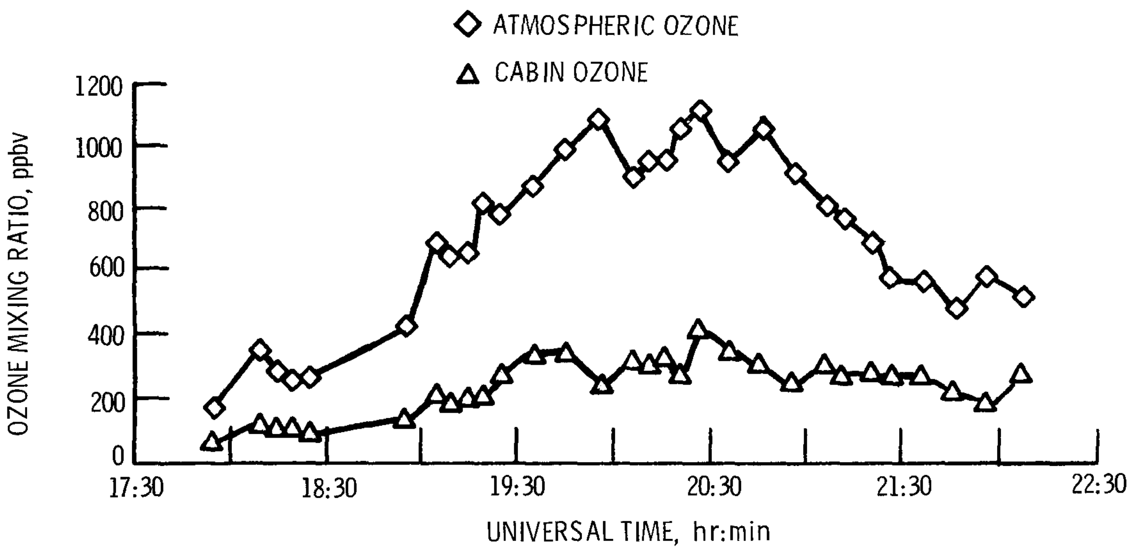

Figure 3. - Time history of ambient and cabin ozone levels for B747-100 airliner flying from New York to Los Angeles on April 3, 1977.

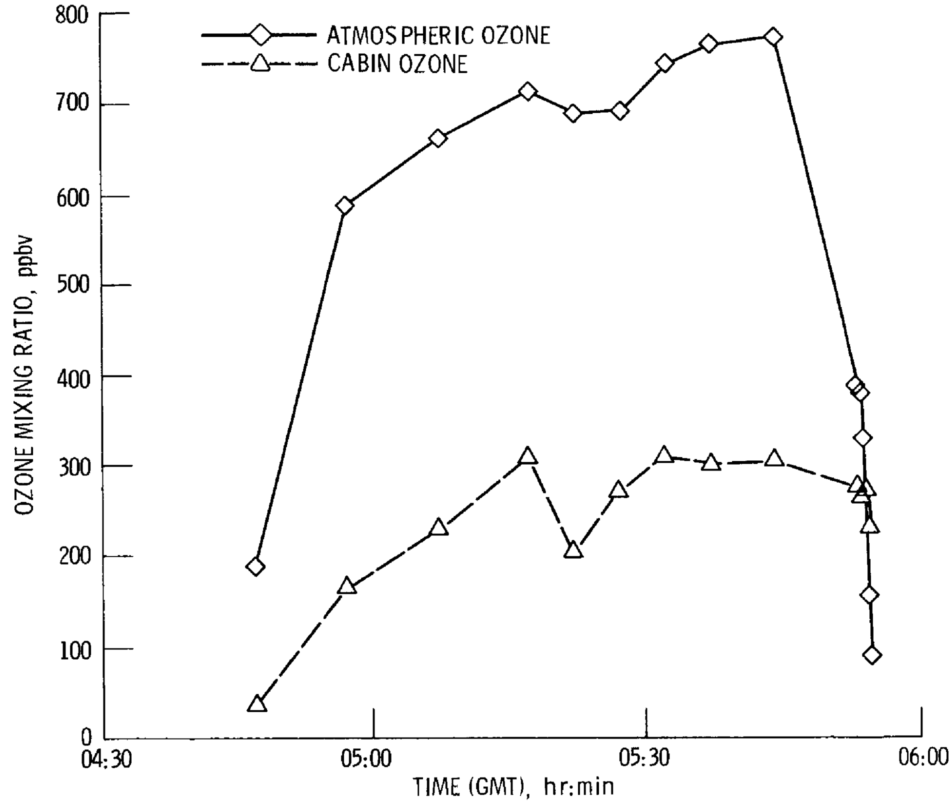

Figure 4. - Time history of atmospheric and cabin ozone levels for B-747 airliner flying from Denver to Chicago on March 8, 1978.

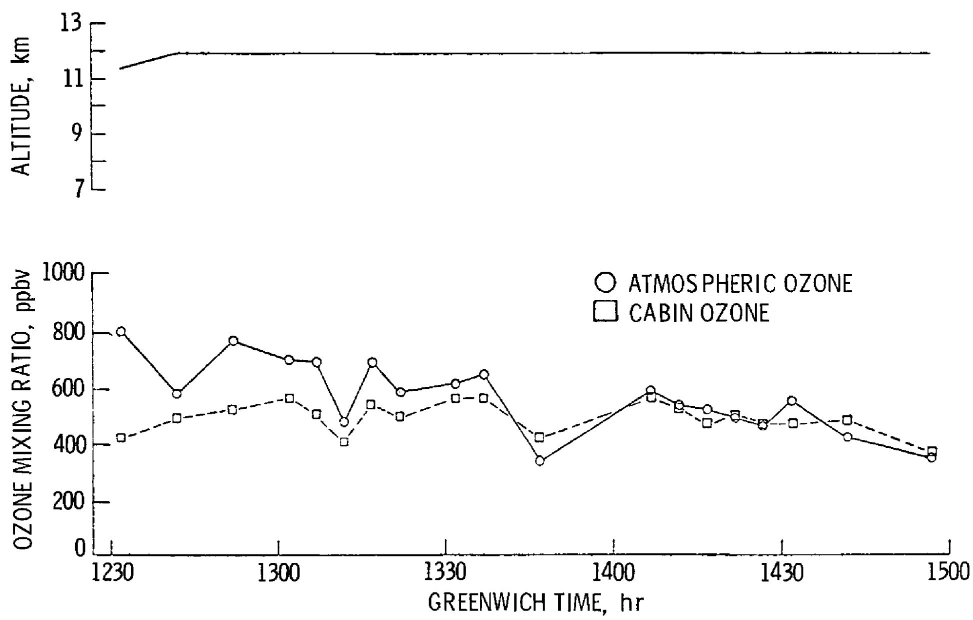

Figure 5. - Time history of cabin and atmospheric ozone mixing ratio levels for B747-SP airliner.

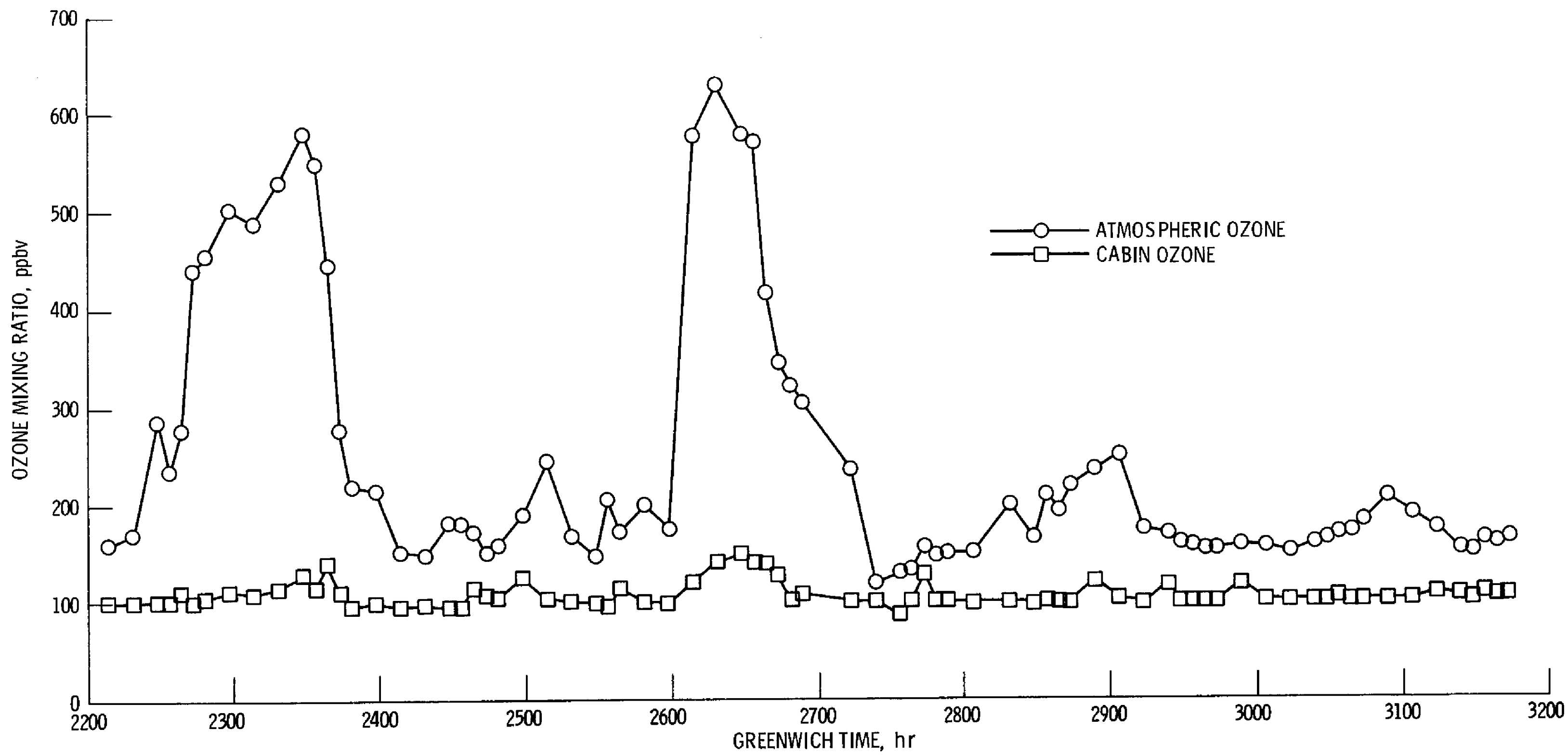

Figure 6. - Time history of ozone concentrations with charcoal filter on aircraft 533 Pa (B747-SP).

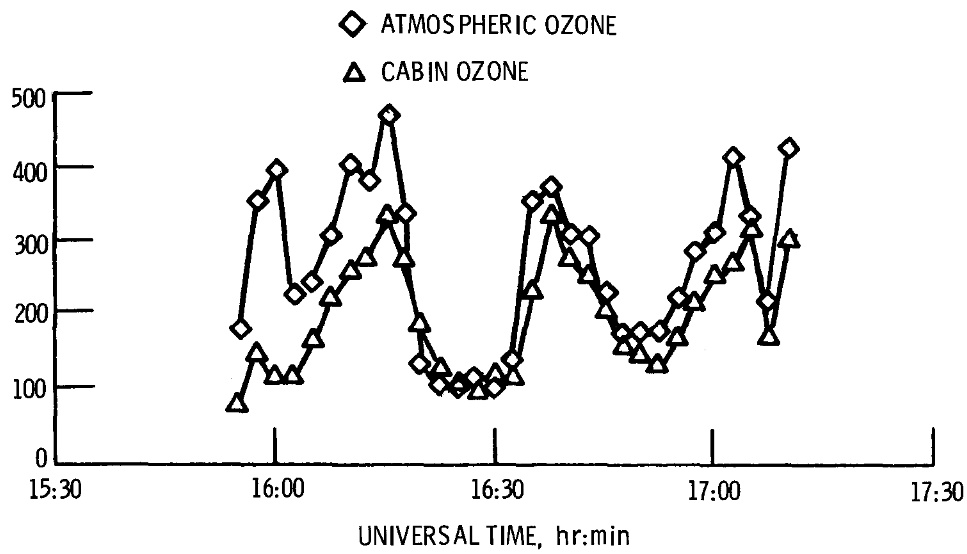

Figure 7. - Comparison of ambient and cabin ozone for Gates Learjet.

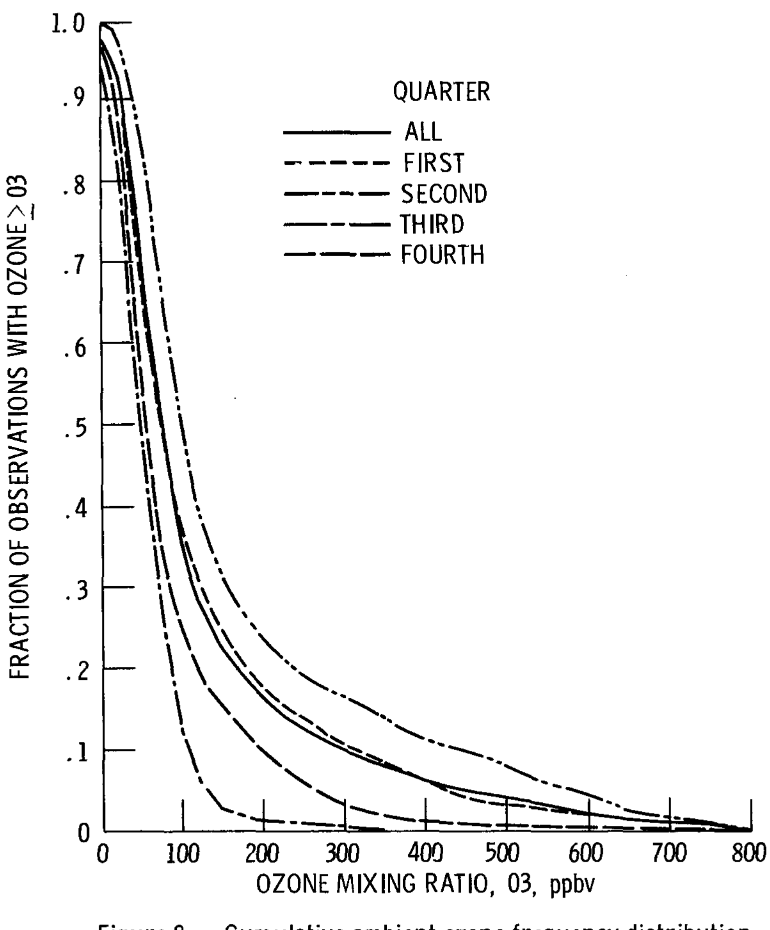

Figure 8. - Cumulative ambient ozone frequency distribution for B747-100 for one year.

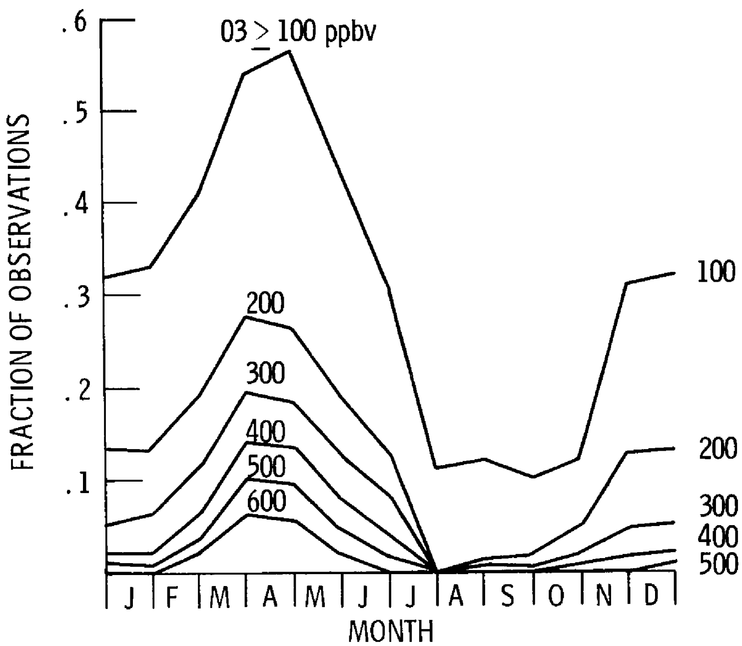

Figure 9. - Bimonthly variation of encounter frequencies for B747-100 for one year.

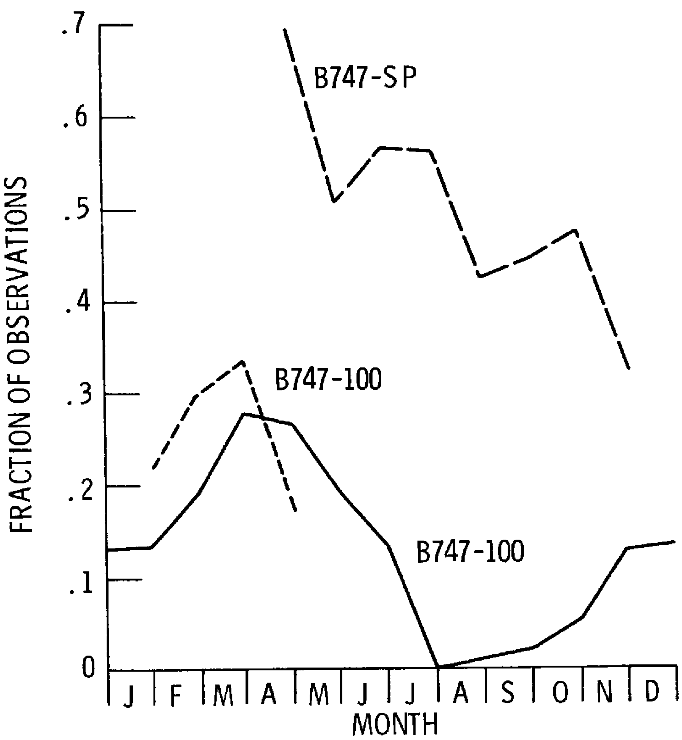

Figure 10. - Bimonthly variation of encounter frequencies for 03 ≥ 200 ppbv.

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Flight Planning to Avoid High Ozone

Arthur D. Belmont
Control Data Corporation

1.0 THE PROBLEM

How to most cost-effectively prevent cabin ozone from exceeding a given standard, for more than a permitted duration or frequency.

Some combination of hardware and flight planning seems a reasonable approach to avoid overdesign.

2.0 QUICK REVIEW OF CABIN OZONE CLIMATOLOGY (See Figures 1-7, Table 1)

2.1 Statistical summaries of the vertical distribution of ozone are available in:

Ref 1: Ozonesonde Data for North America, 1962-1975, at standard atmosphere altitudes, Aug 1977.

Ref 2: FAA Guidelines for Flight Planning, Jan 1978. As an improvement over climatological average ozone, guidelines are presented for estimating ozone in terms of forecast temperature, for each flight level, in the stratosphere, by season and latitude. This was prepared in two months as a stop-gap measure. Careful study is still needed. Only 22 months of GASP data were available (Mar 1975 - Dec 1976).

Ref 3: Contract report to NASA-Lewis on GASP data near the tropopause, Apr 1978. This summarizes GASP data from 11 to 12 km true altitudes.

3.0 CONSIDERATIONS

3.1 Many Factors: Cost, logistics, simplicity, maintenance, ability to forecast high ozone quantitatively and to determine its location, ease and cost of avoiding high ozone if ozone forecasts to be observed, frequency of excess ozone.

4.0 POSSIBLE APPROACHES

4.1 Super Filter: Used on all aircraft to remove all ozone always, will be needlessly expensive if there are many routes, times, and altitudes when ozone is below limits.

4.2 Medium Filter: Removes ozone up to some percentage of ambient, so that cabin concentration will usually be below established limit. Use flight planning to avoid higher concentrations.

4.3 Flexible Filter: Use only as strong a filter as required by climatology for each particular route, season, and altitude, but use no filter in low latitudes, altitudes, or seasons where climatology shows seldom needed. Use flight planning to avoid occasional regions of forecast high concentrations. Filter must be easily installed or turned on.

4.4 No Filter: Circulate air in cabin less often when high outside ozone is present. Add odorless, harmless oxidants to decompose ozone. Avoid regions of maximum ozone by flight planning.

5.0 REQUIREMENTS

To help make pı ɾ decision, the following information is needed:

5.1 How well can ozone be forecast operationally by either Flight Planners or NMC? Development of a good forecast system would require a one year study.

5.2 Frequency distribution of GASP ozone data is needed by latitude belt, season, flight level. Update each year as more GASP data become available.

5.3 Consider trade-offs between hardware and operational forecast avoidance of highest ozone.

5.4 From 5.2, determine maximum ozone concentration for which filters should be designed as in Figure 8, for example. For a reliable frequency distribution, where should the limit for filters be set? Is it necessary to have filters to take care of the 3% (or 20%) occurrence of extreme ozone?

REFERENCES

1. Wilcox, R. W. and A. D. Belmont, 1977: Ozone concentration by latitude, altitude, and month, near 80°W. Contract DOT-FA77WA-3999 for Federal Aviation Administration; Report No. FAA-AEQ-77-13, by Research Division, Control Data Corporation, Minneapolis, 41pp.

2. Belmont, A. D., R. W. Wilcox, G. D. Nastrom, D. N. Hovland, and D. G. Dartt, 1978: Guidelines for flight planning during periods of high ozone occurrence. Contract DOT-FA77WA-4074 for Federal Aviation Administration; Report No. FAA-EQ-78-03, by Research Division, Control Data Corporation, Minneapolis, 156pp.

3. Nastrom, G. D., 1978: Variability of ozone near the tropopause from GASP data. Contract NAS3-20618 for NASA-Lewis Research Center; Research Report No. 1, by Research Division, Control Data Corporation, Minneapolis, 45pp; CR-135405, April 1978.

TABLE I. - GASP OZONE DATA (PPBV) FROM 11 TO 12 KM TRUE ALTITUDE AS A FUNCTION OF LATITUTDE AND LONGITUDE

[The plotting code is in the upper left box. The right hand column is the zonal mean, and the max is the largest value at that latitude. The standard deviation (σ) is not given for fewer than ten observations.]

LAT	120E–170E	170E–140W	140W–90W	90W–40W	40W–10E	10E–60E	60E–120E	M
N 66 and above	Mean N Max σ	315 13 656 124	299 11 541 144					307 24 565 133
N 66–60		345 22 561 155	161 14 296 89		60 4 121			252 40 561 166
60–54				96 37 497 139	195 24 429 152			135 61 497 152
54–48			216 90 1028 195	266 54 1074 266	261 23 497 142			238 167 1074 216
48–42	190 9 282		145 445 604 111	182 51 690 133				149 505 690 113
42–36		41 30 209 37	88 394 519 76					85 424 519 75
36–30		55 282 373 41	81 87 235 46					61 369 373 44
30–24		48 132 129 29	52 26 108 24				93 4 264	50 162 264 33
24–18	3 40 26 5	31 57 84 18	32 3 35				21 3 24	20 103 84 19
18–12		31 31 54 11						31 31 54 11
12–6		27 48 45 8						27 48 45 8
6–0		31 62 57 10						31 62 57 10
0–S 6		29 59 54 11						29 59 54 11
S 6–12		38 65 99 21						38 65 99 21
12–18		55 30 145 31						55 30 145 31
18–24	109 3 116	100 25 175 48						101 28 175 46
24–30	211 27 345 93	148 17 283 61						187 44 345 88
30–36	213 6 279	174 13 318 70						186 19 318 68
36–42								

December, January, February

LAT	120E–170E	170E–140W	140W–90W	90W–40W	40W–10E	10E–60E	60E–120E	M
–N 66	Mean N Max σ	484 9 584	483 30 937 154		540 9 598			493 48 937 127
N 66–60		475 2 491	417 23 886 203	625 15 803 151	341 83 700 168			392 123 886 195
60–54	733 7 1169	472 22 1159 237	376 16 697 233	425 93 983 199	292 148 640 173	374 2 428		364 288 1169 213
54–48	288 16 777 209	293 60 669 180	420 199 994 233	347 157 808 192	140 26 517 138	411 31 801 172		361 489 994 218
48–42	184 41 596 153	332 32 635 184	290 641 964 221	222 36 825 217		294 4 464		283 754 964 218
42–36	131 33 324 74	109 76 265 45	127 421 582 100	126 21 580 140		229 29 538 165		130 580 582 102
36–30	84 40 142 26	92 372 378 41	89 84 143 33	61 13 96 19		130 1 130	81 66 159 29	89 576 378 38
30–24	52 48 96 20	77 265 293 46	39 43 255 45	51 7 60			52 66 112 29	66 429 293 43
24–18	40 143 104 18	92 30 138 23	45 40 108 29	36 81 93 22			21 41 59 16	42 335 138 27
18–12				31 103 89 19			38 15 45 5	32 118 89 18
12–6				19 50 46 12				19 50 46 12
6–0				13 30 45 15				13 30 45 15
0–S 6				24 19 45 14				24 19 45 14
S 6–12				19 13 38 9				19 13 38 9
12–18				6 1 6				6 1 6
18–24								
24–30								
30–36								
36–42								

March, April, May

LAT	120E–170E	170E–140W	140W–90W	90W–40W	40W–10E	10E–60E	60E–120E	M
–N 66	Mean N Max σ	314 13 374 37	313 17 359 28					314 30 374 33
N 66–60		280 69 499 104	356 9 405	231 13 343 97	291 63 397 83			285 153 499 95
60–54	341 2 344	219 31 479 133	288 22 463 132	152 60 437 117	179 95 360 106	127 7 179		188 217 479 122
54–48		302 19 393 89	125 65 409 106	99 106 344 67	175 7 195	171 22 336 64		134 219 409 99
48–42	34 7 48		115 239 549 97	86 8 221		80 45 194 38		107 299 549 90
42–36	32 9 59	79 24 189 41	71 281 393 67			53 121 125 17		66 435 393 57
36–30	51 3 83	55 223 174 28	73 99 514 103			40 29 69 8	39 50 98 16	56 404 514 56
30–24		52 136 191 29				41 1 41	33 36 65 9	48 173 191 27
24–18	18 2 24	20 29 36 6		30 3 39			27 56 53 10	25 90 53 9
18–12	16 6 19	18 55 29 5		31 7 44			25 53 65 13	22 121 65 10
12–6	15 5 18	17 52 27 6		23 4 24			24 24 46 10	19 85 46 8
6–0								
0–S 6		20 5 22						20 5 22
S 6–12		19 1 19						19 1 19
12–18								
18–24								
24–30	124 20 178 38						76 5 123	115 25 178 41
30–36								
36–42								

June, July, August

LAT	120E–170E	170E–140W	140W–90W	90W–40W	40W–10E	10E–60E	60E–120E	M
N 66	Mean N Max σ	340 170 653 106	255 116 542 127					305 286 653 122
60		324 285 661 107	248 136 537 116	262 25 540 145	188 135 439 111			272 581 661 125
54	283 38 562 171	273 138 573 118	143 46 337 74	91 176 389 80	126 195 475 96			161 593 573 127
48	91 93 338 72	176 88 401 101	129 85 509 126	92 282 376 72	60 19 106 20			109 567 509 92
42	74 152 324 49	147 2 217	80 305 441 73	99 48 321 65		53 17 65 7		80 524 441 65
36	45 3 71	41 27 74 23	55 366 284 31	36 19 45 5		43 7 50		53 422 284 30
30		43 249 137 24	46 53 116 27	32 19 47 6			42 17 56 7	43 338 137 23
24		38 92 102 22	59 9 72	31 15 47 7			44 10 83 14	39 126 102 20
18		34 3 51	52 4 58	46 25 93 19			9 1 9	45 33 93 19
12		41 6 48		53 26 74 9				51 32 74 10
6		35 4 47		65 25 108 23				61 29 108 24
0				68 49 109 21				68 49 109 21
S 6				60 44 83 15				60 44 83 15
12		50 10 104 28		55 49 85 13				54 59 104 16
18		86 1 86		60 21 100 18				61 22 100 18
24								
30	130 5 174							130 5 174
36	196 6 235							196 6 235
42		231 2 255						231 2 255

September, October, November

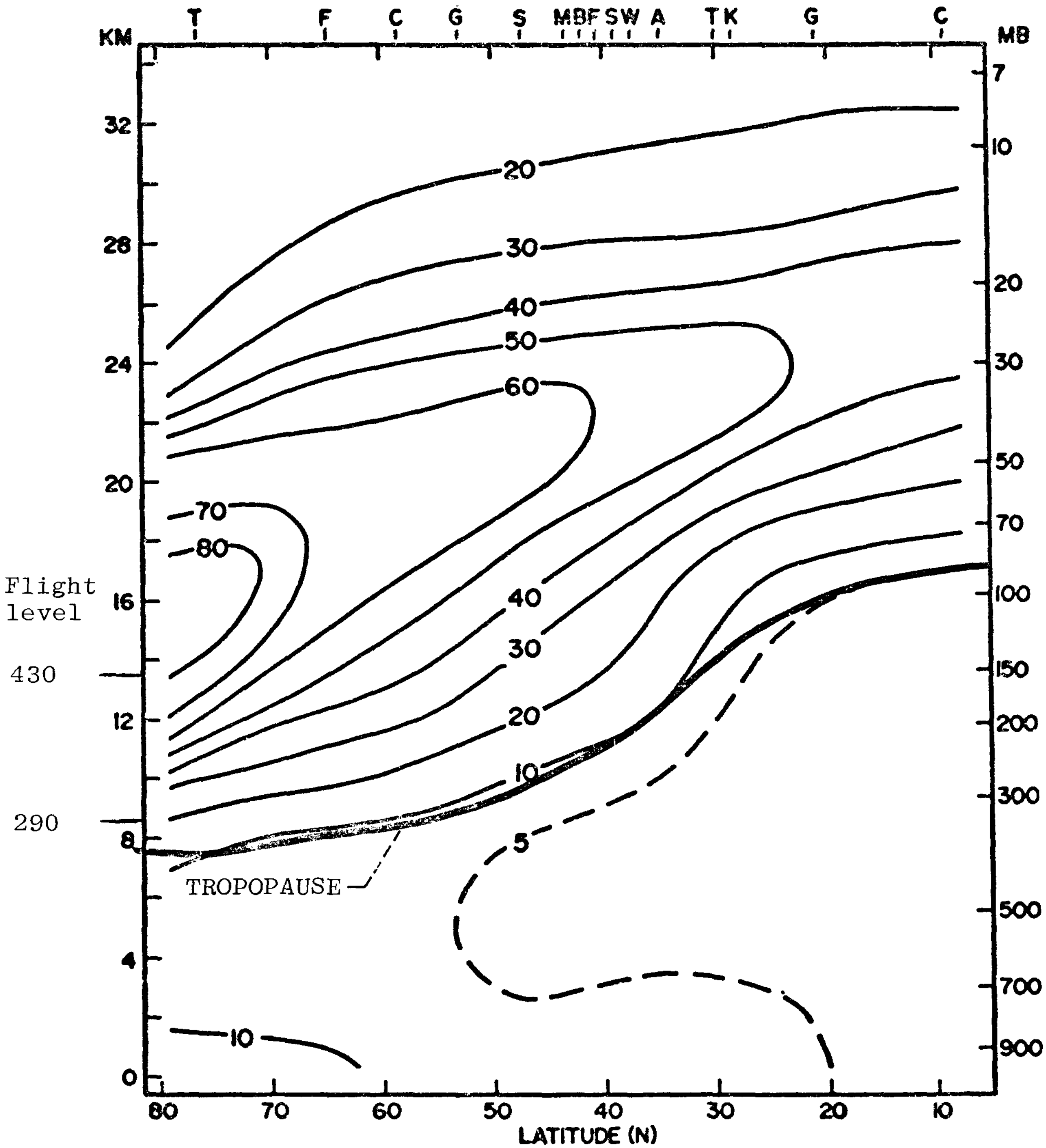


Figure 1. - Vertical distribution of ozone concentration for January over North America. Units are 10^{11} molecules cm^{-3}. Ozonesonde stations used are indicated at top of figure; see Table 2 for periods of record at each. (From J. of Appl. Meteor., vol. 16, p. 293.)

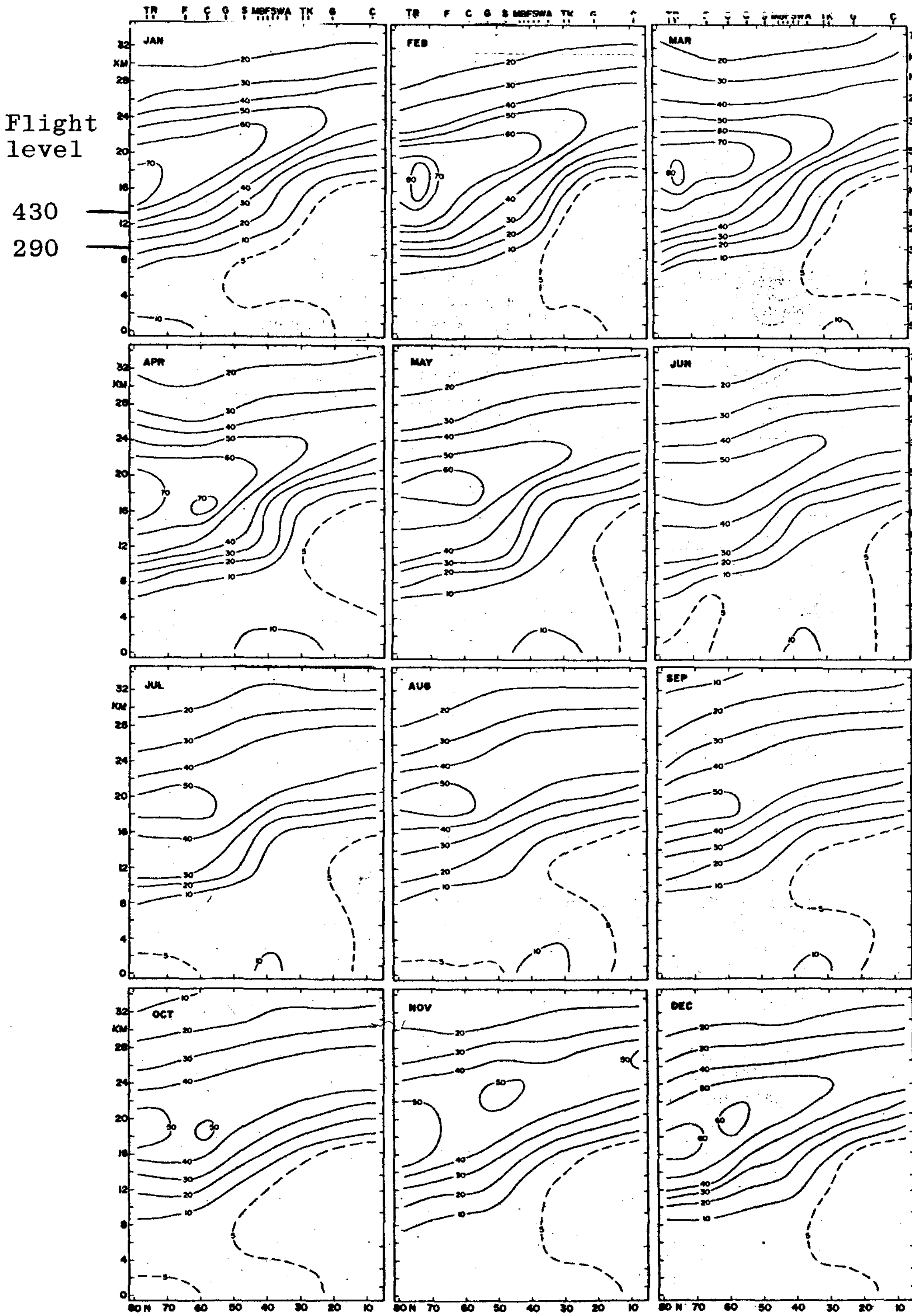


Figure 2. - Vertical distribution of ozone over North America by month. Units are 10^{11} molecules cm^{-3}. Ozonesonde stations are indicated at the top of the figure. (From J. of Appl. Meteor., vol. 16, p. 293.)

DECEMBER - FEBRUARY

PPMV

MEAN

KM	80N	70	60	50	40	30	20	10
32.5	6.3	6.5	6.3	5.8	6.2	7.3	8.0	8.3
30.0	6.0	6.3	6.2	5.7	6.2	7.0	8.0	8.3
27.5	5.7	6.2	6.1	5.7	6.2	6.7	7.0	7.6
25.0	5.5	6.0	5.9	5.5	5.8	5.8	5.7	5.7
22.5	5.0	5.2	5.2	5.0	4.9	4.3	3.5	3.1
20.0	4.3	4.1	3.8	3.5	3.0	2.1	1.3	.9
17.5	3.4	3.1	2.4	1.8	1.3	.6	.3	.2
15.0	2.4	1.9	1.4	1.0	.5	.2	.08	.06
12.5	1.2	.9	.6	.4	.3	.1	.04	.03
10.0	.5	.4	.2	.2	.1	.06	.03	.03
7.5	.1	.1	.08	.07	.06	.04	.03	.03
5.0	.04	.04	.04	.03	.04	.03	.03	.02
2.5	.04	.04	.03	.03	.04	.03	.03	.02

STANDARD DEVIATION

KM	80N	70	60	50	40	30	20	10
32.5	2.3	2.0	1.4	1.1	1.2	1.0	1.2	1.0
30.0	2.2	1.8	1.3	1.1	1.0	.9	.9	.9
27.5	1.9	1.5	1.2	.9	.8	.8	.7	.7
25.0	1.4	1.2	1.1	.8	.7	.6	.6	.6
22.5	1.1	1.0	.9	.7	.7	.5	.5	.5
20.0	.8	.8	.7	.7	.6	.5	.4	.3
17.5	.7	.6	.6	.6	.5	.3	.15	.08
15.0	.6	.5	.5	.4	.4	.10	.03	.02
12.5	.4	.4	.3	.3	.2	.07	.02	.01
10.0	.15	.15	.15	.10	.09	.03	.01	.01
7.5	.05	.05	.05	.04	.03	.02	.01	.01
5.0	.01	.01	.02	.01	.02	.01	.01	.01
2.5	.01	.01	.02	.01	.01	.01	.01	.01

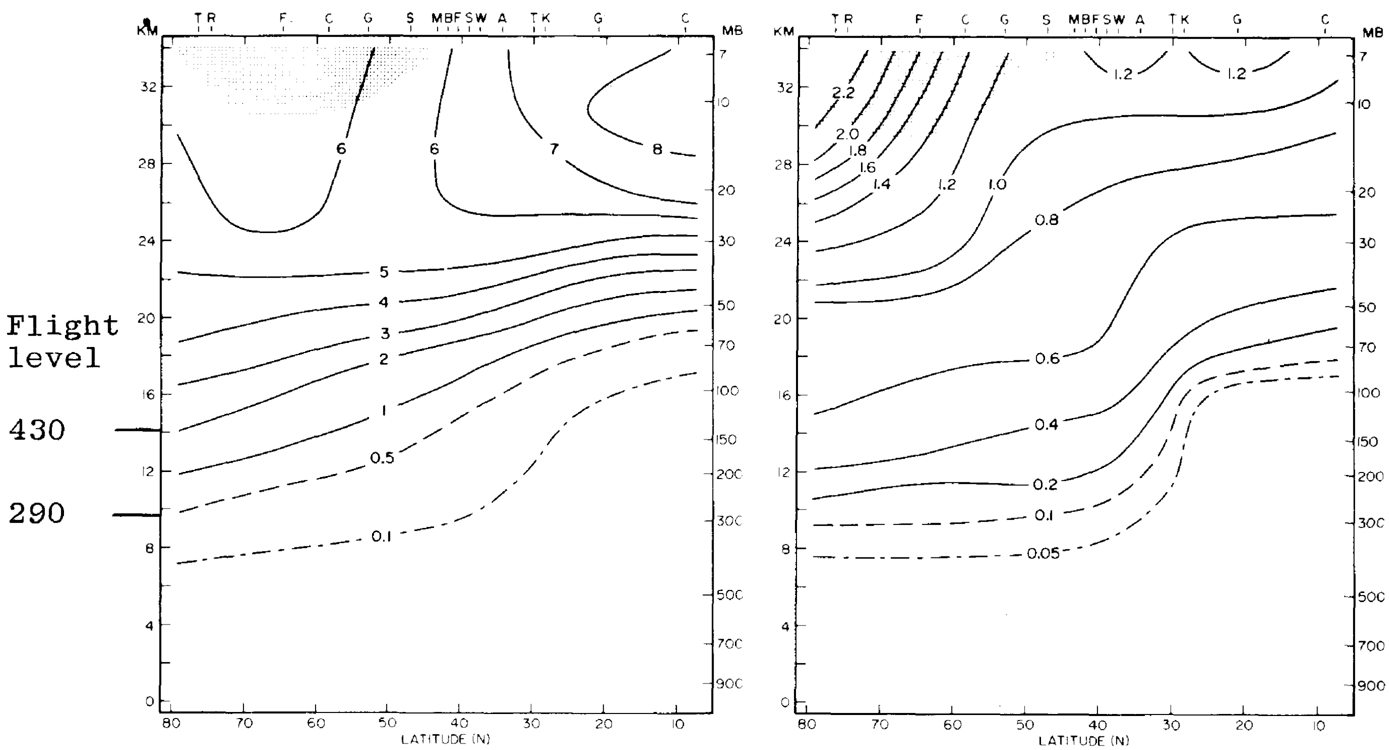


Figure 3. - Seasonal height-latitude cross-sections of ozone means and standard deviations near 80°W in units parts per million by volume. Shaded areas have no data. The pressure scale is approximate, based on the annual mid-latitude average (Ref. 1).

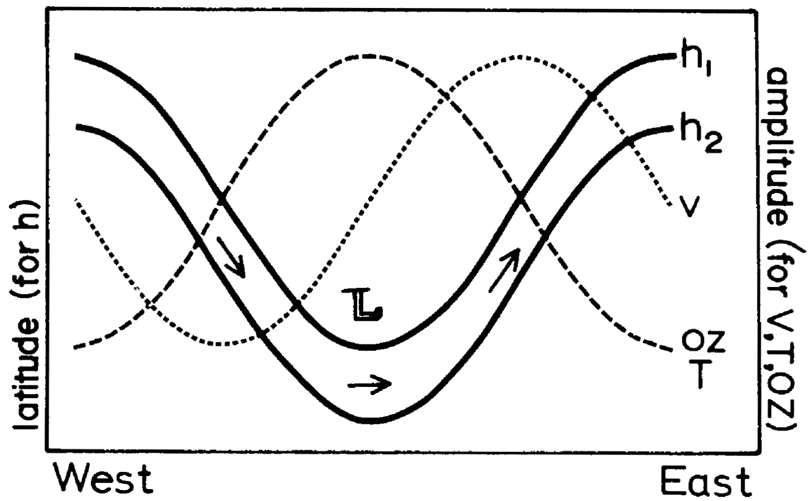


Figure 4. - Schematic picture showing the phase relations between pressure-height, geostrophic meridional wind, and ozone and temperature. At a given pressure near the tropopause, largest ozone is found with lowest height (Ref. 3).

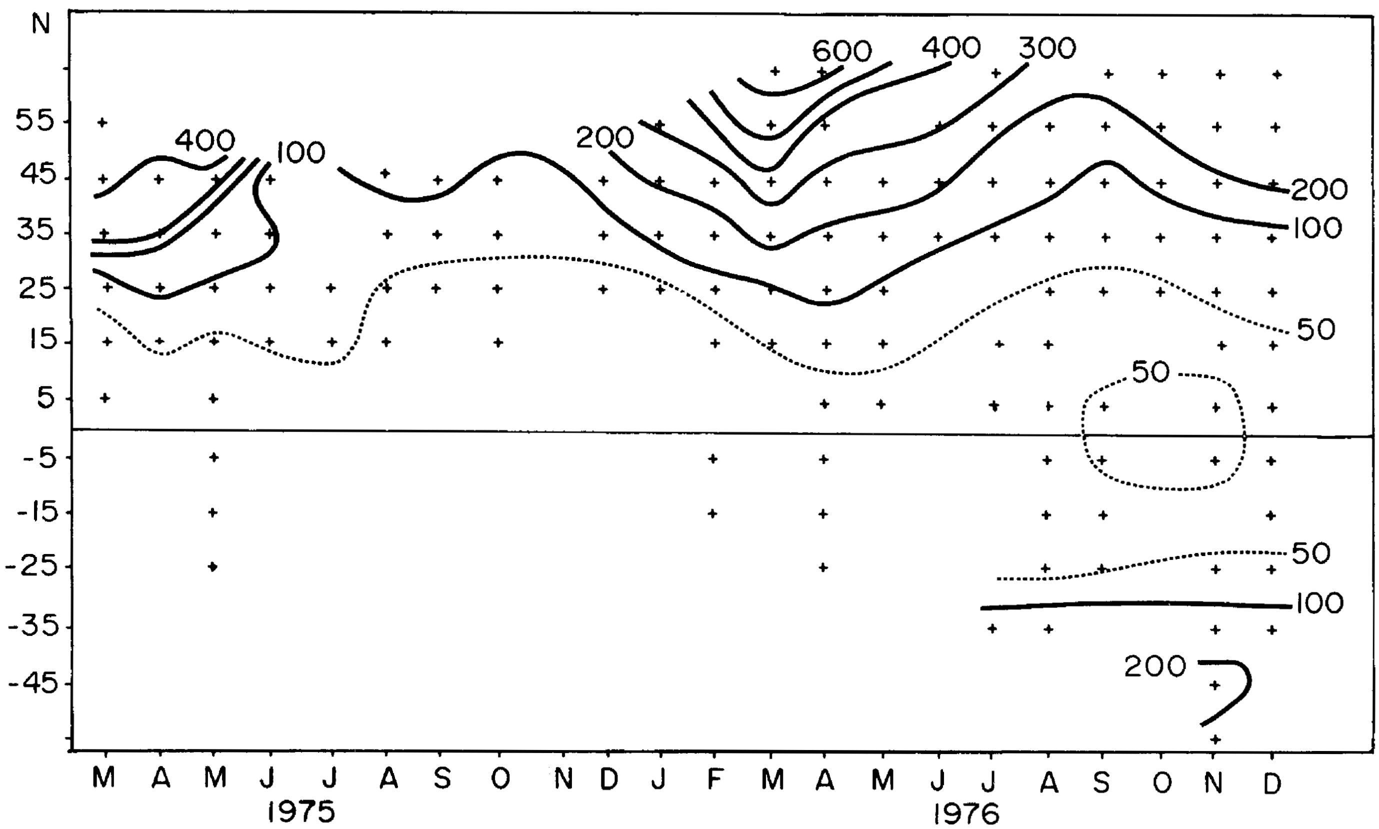


Figure 5. - Zonal-monthly mean ozone amount (ppbv) for data taken at 217 hPa (37000 ± 1000 feet in the standard atmosphere, or about 11.3 km). Those grid points with data are depicted by small crosses (Ref. 3).

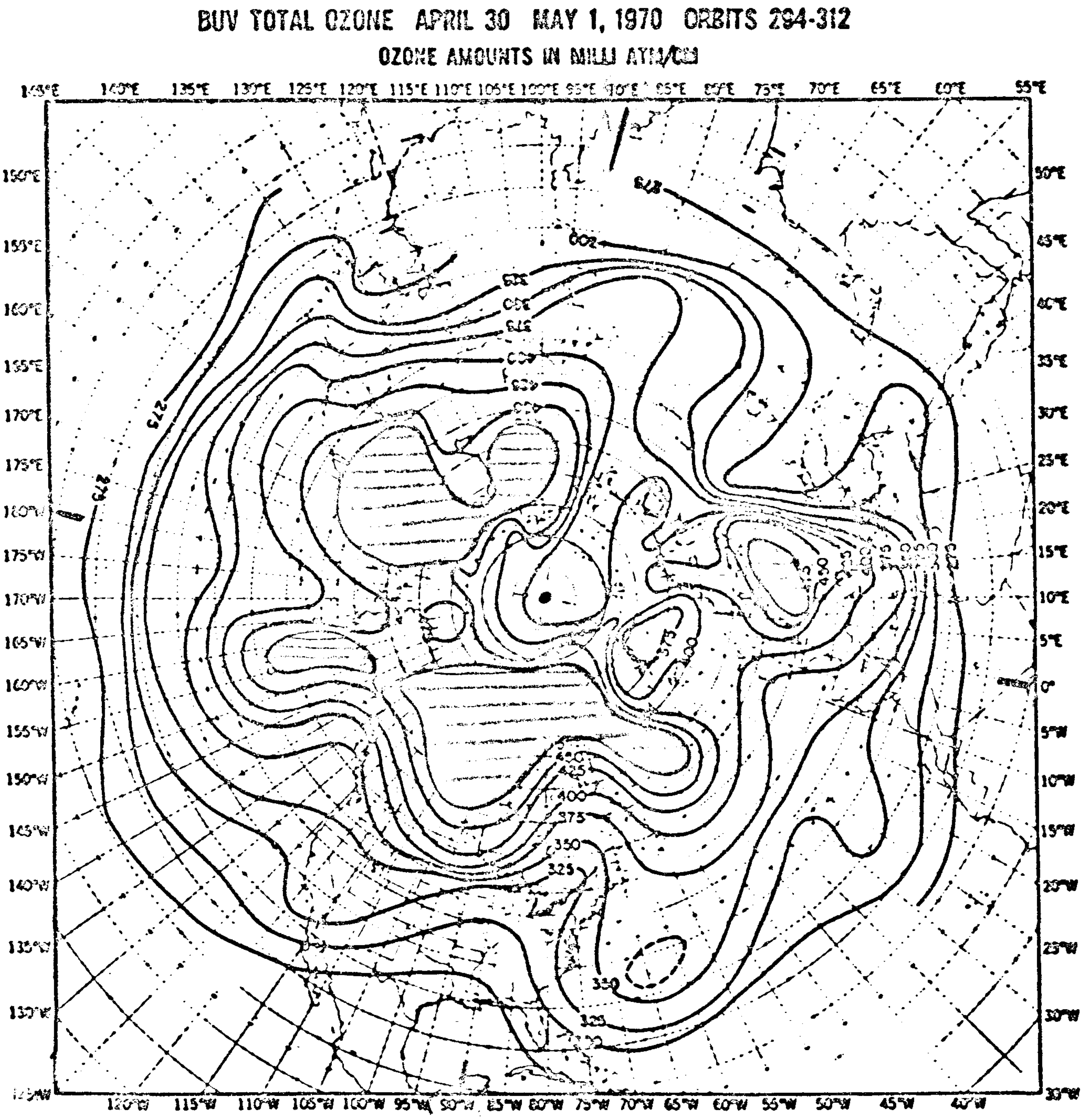


Figure 6. - Total ozone contours (in milliatm/cm) for Northern Hemisphere, Derived from BUV measurements on April 30 and May 1, 1970. Areas of maximum ozone are hatched. (Taken from Heath, et al., 1973.)

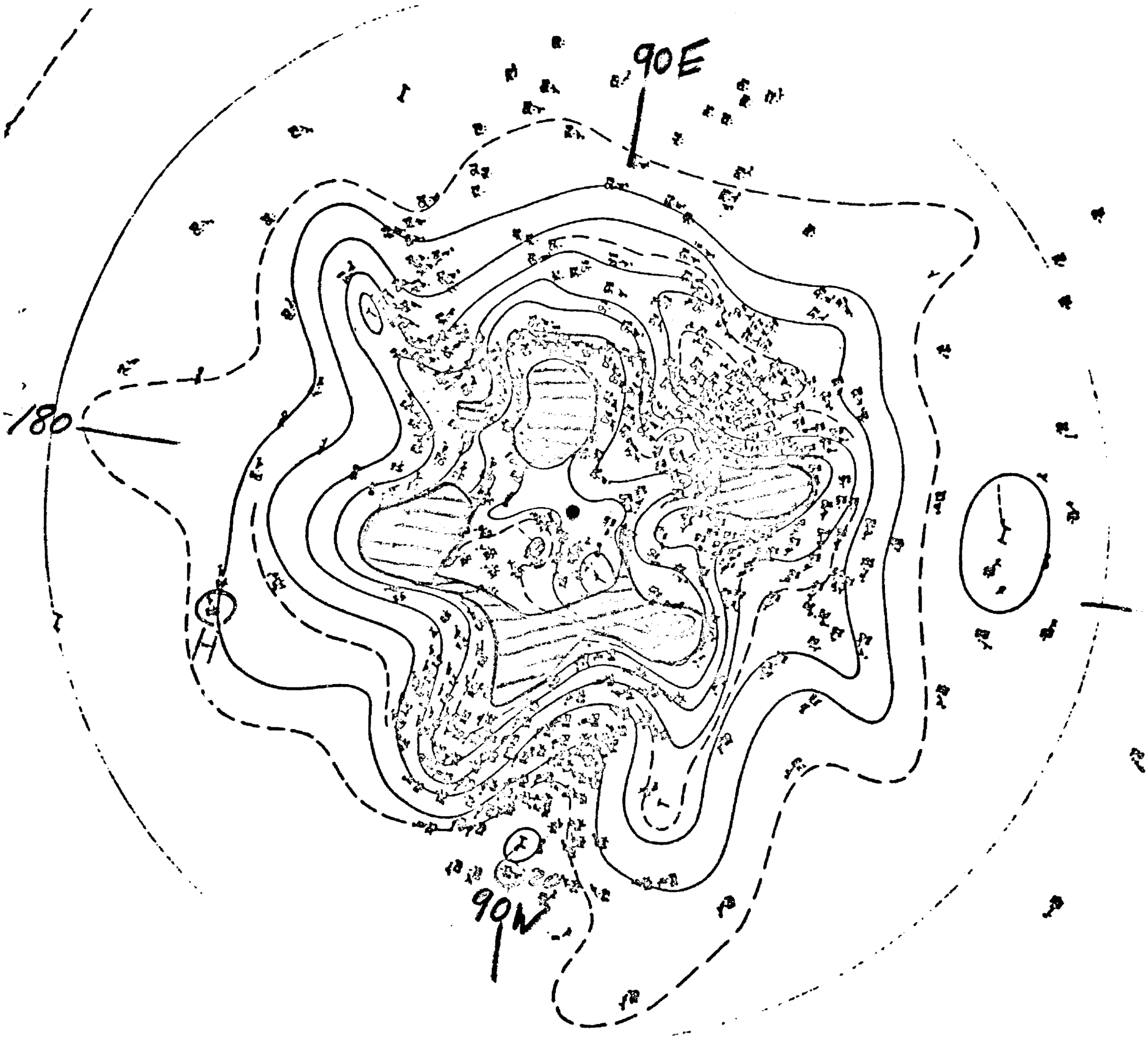


Figure 7. - 300-mb height contours on May 1, 1970. Note that areas of lowest height correspond very closely to areas of maximum ozone in Figure 6. Areas of maximum ozone are hatched.

Ambient	Cabin: No filter (50% natural reduction)	Cabin: 75% filter	Cabin: 90% filter
1.10	.55	.14	.06
1.00	.50	.13	.05
.90	.45	.11	.05
.80	.40	.10	.04
.70	.35	.09	.04
.60	.30	.08	.03
.50	.25	.06	.03
.40	.20	.05	.02
.30	.15	.04	.02
.20	.10	.03	.01
.10	.05	.01	.01
.00	.00	.00	.00

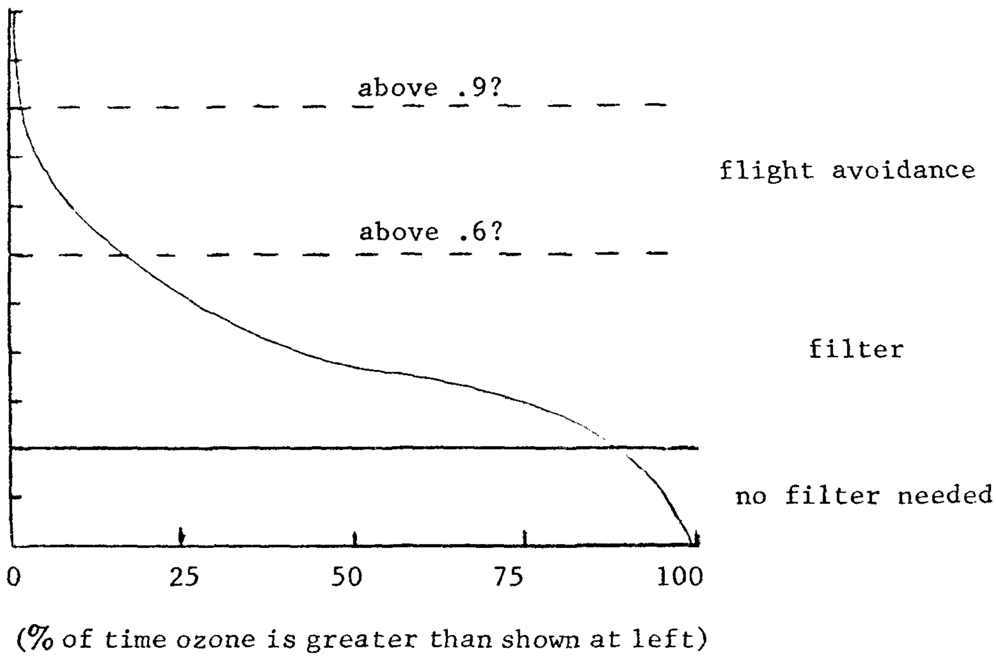


Figure 8. - Hypothetical cumulative frequency distribution of ambient ozone greater than shown in left column. Two possible levels of ozone concentration above which flight planning is advisable are shown as examples. Cabin ozone is assumed to be 50% of ambient. Such distributions will vary greatly depending on altitude, season, latitude.

Ozone Destruction Techniques

Ray Wilder
The Boeing Co.

FIG. 1. OZONE FILTER TEST PROGRAM

- FLIGHT TESTS ON RA001
- SMALL SCALE LAB TESTS
  - FILTER MATERIALS SURVEY
  - ACCELERATED LIFE TESTS
- FULL SCALE LAB TESTS
  - DESIGN VERIFICATION TESTS
  - FLAME
  - VIBRATION
  - ACCELERATED CONTAMINATION
  - LIFE CYCLE
  - CABIN AIR QUALITY

FIG. 2. OZONE INSTRUMENTATION

Lab Test Ozone Monitors

- Ultra-Violet Adsorption Type
  - Dasibi Corp. Model 1003
- Chemiluminescent Type
  - Columbia Scientific Ind. (CSI Model 2000)
  - Analytical Instrument Development, Inc. (AID Model 560)

FIG. 3. OZONE ANALYZER SCHEMATIC - ULTRA-VIOLET LIGHT ADSORPTION TYPE

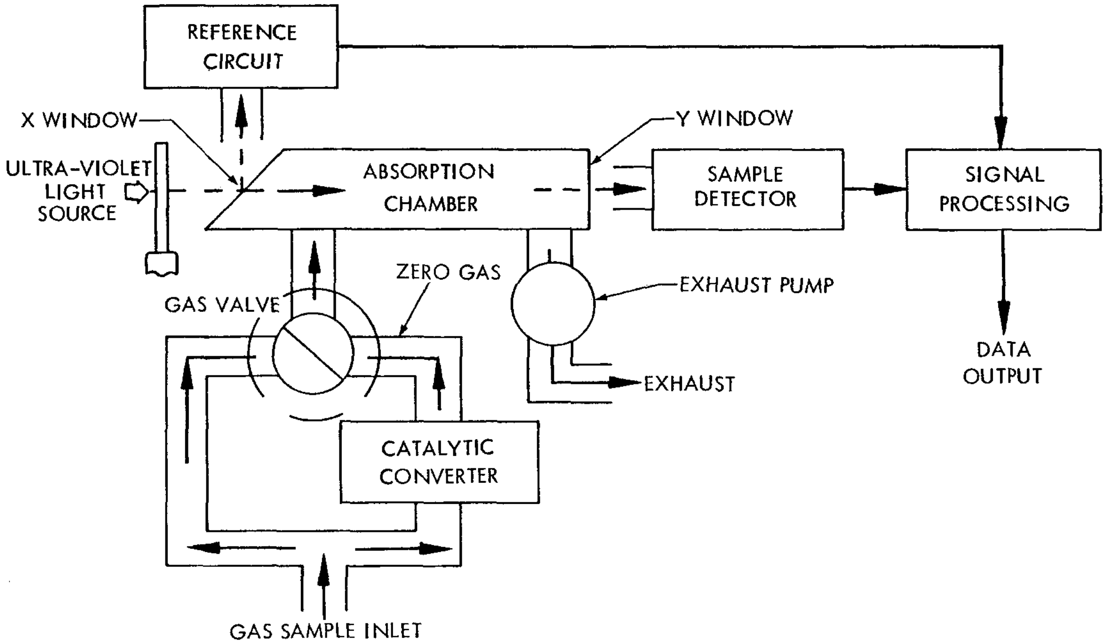


FIG. 4. OZONE ANALYZER SCHEMATIC - CHEMILUMINESCENT TYPE

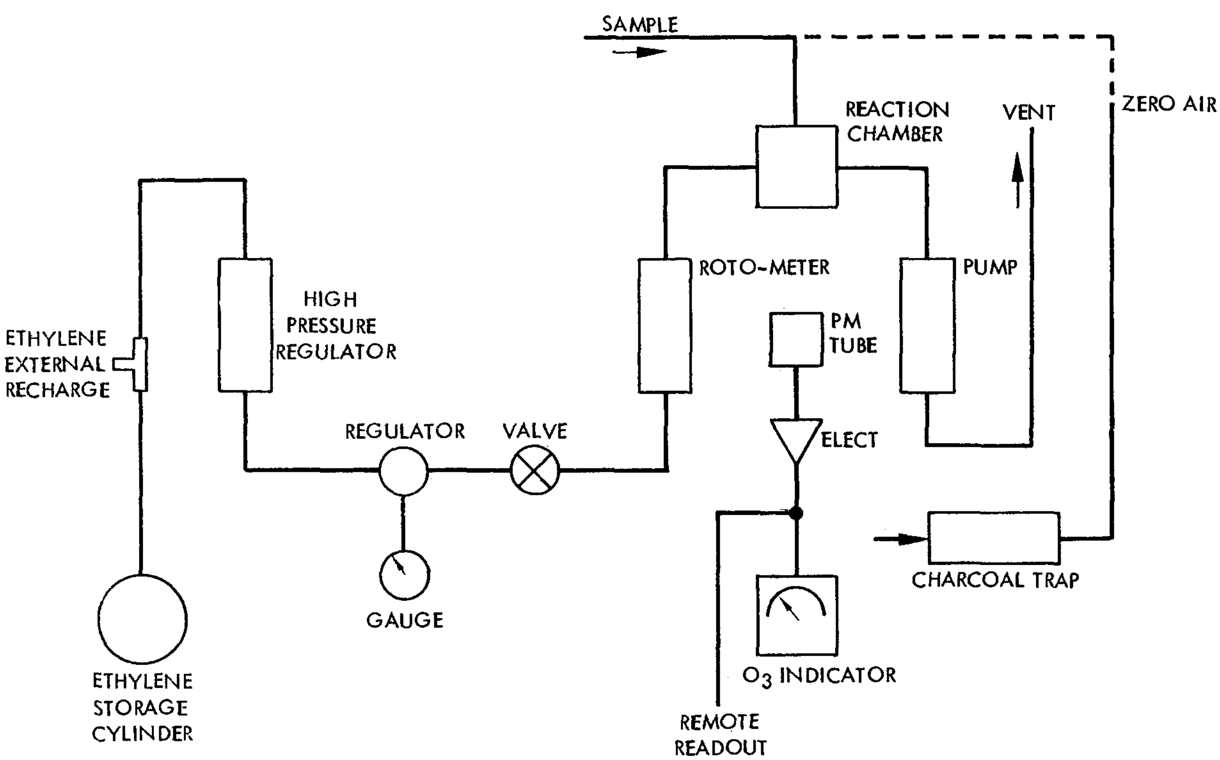


FIG. 5. SMALL SCALE OZONE FILTER TEST SETUP

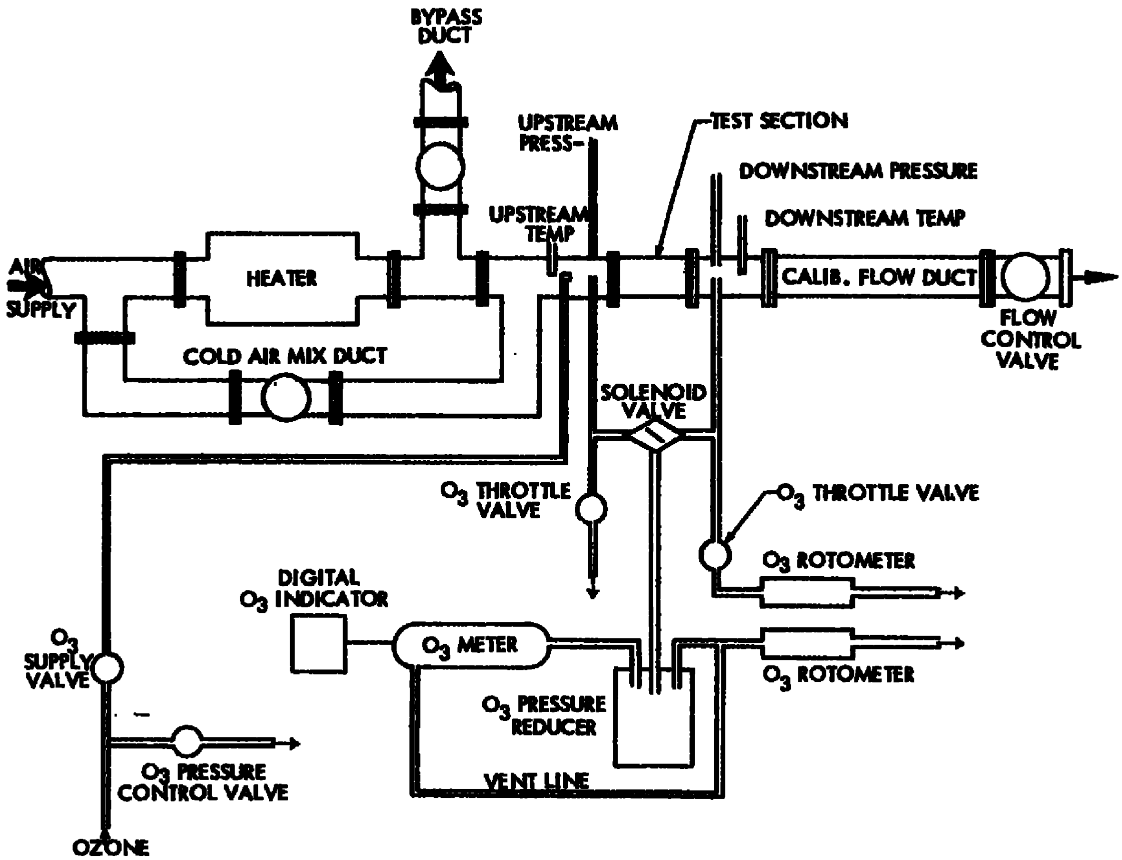
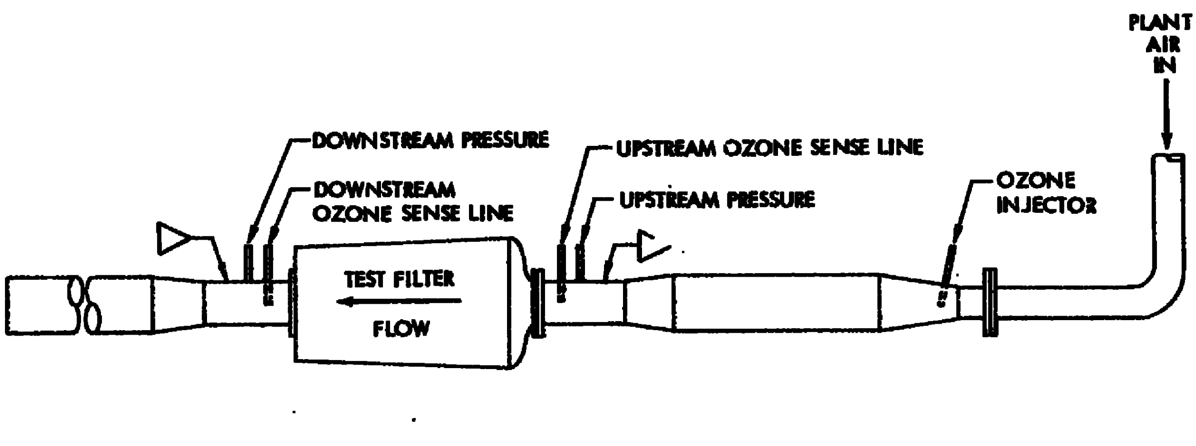
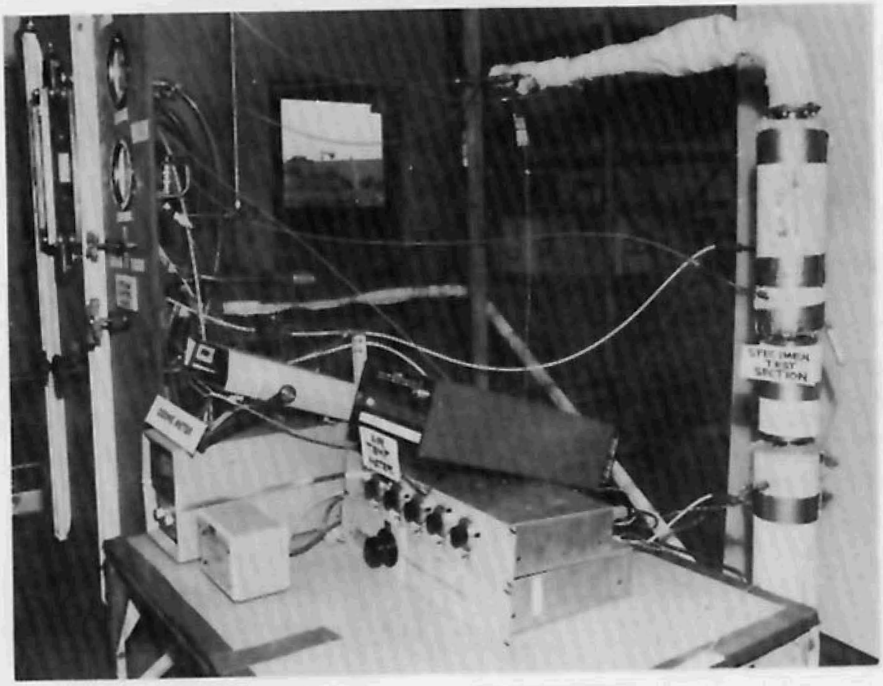


FIG. 6. FULL SCALE PRODUCTION FILTER FUNCTIONAL LAB TEST - TEST SETUP SCHEMATIC



▷ UPSTREAM & DOWNSTREAM TRANSITION SAME DIAMETER AS FILTER BEING TESTED

FIG. 7. PNEUMATIC DUCT - LAB TEST PHOTOS



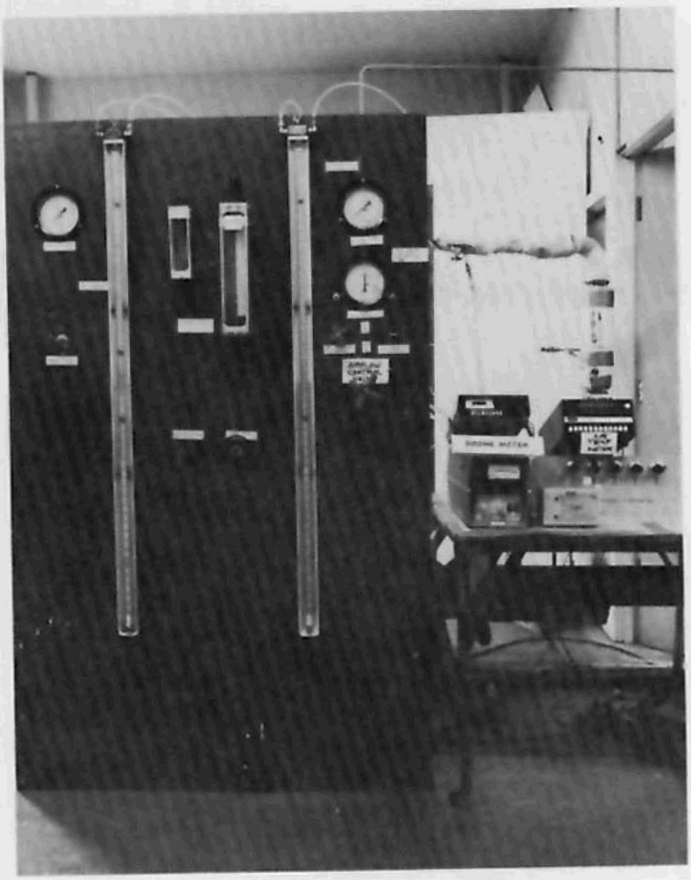
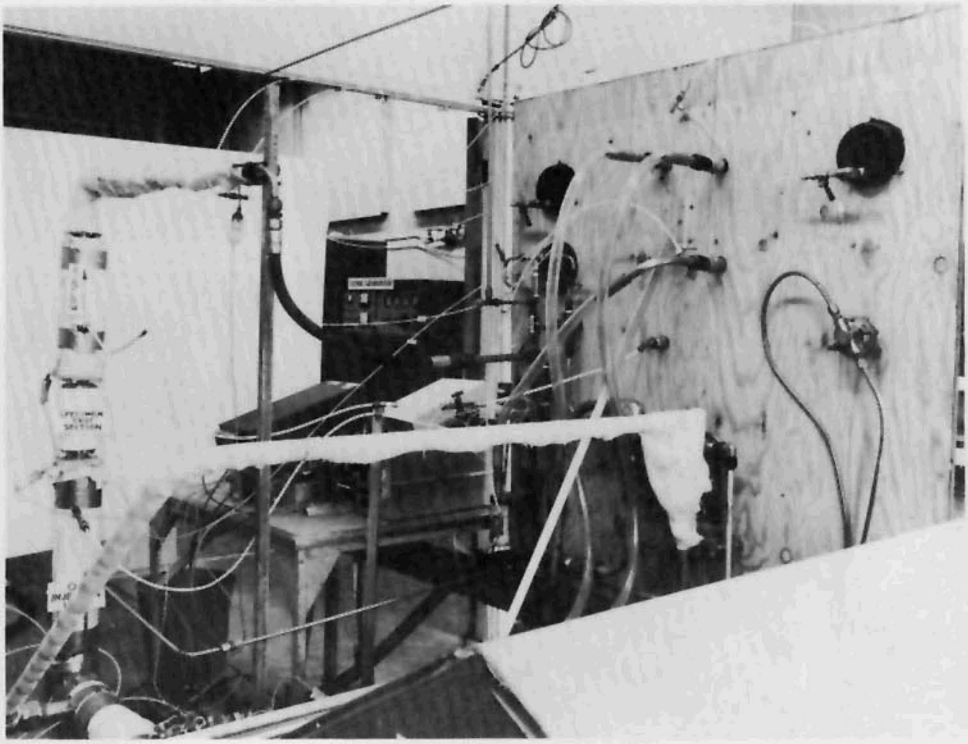


FIG. 8. FULL SCALE LAB TEST PHOTOS



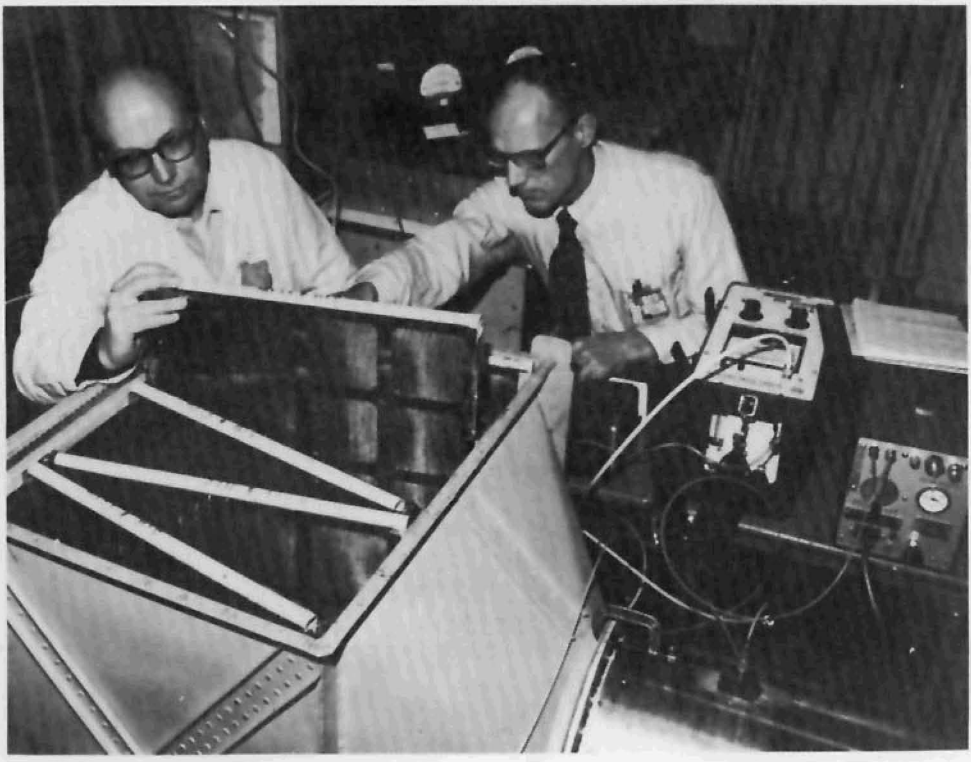


FIG. 9. FULL SCALE LAB TESTS

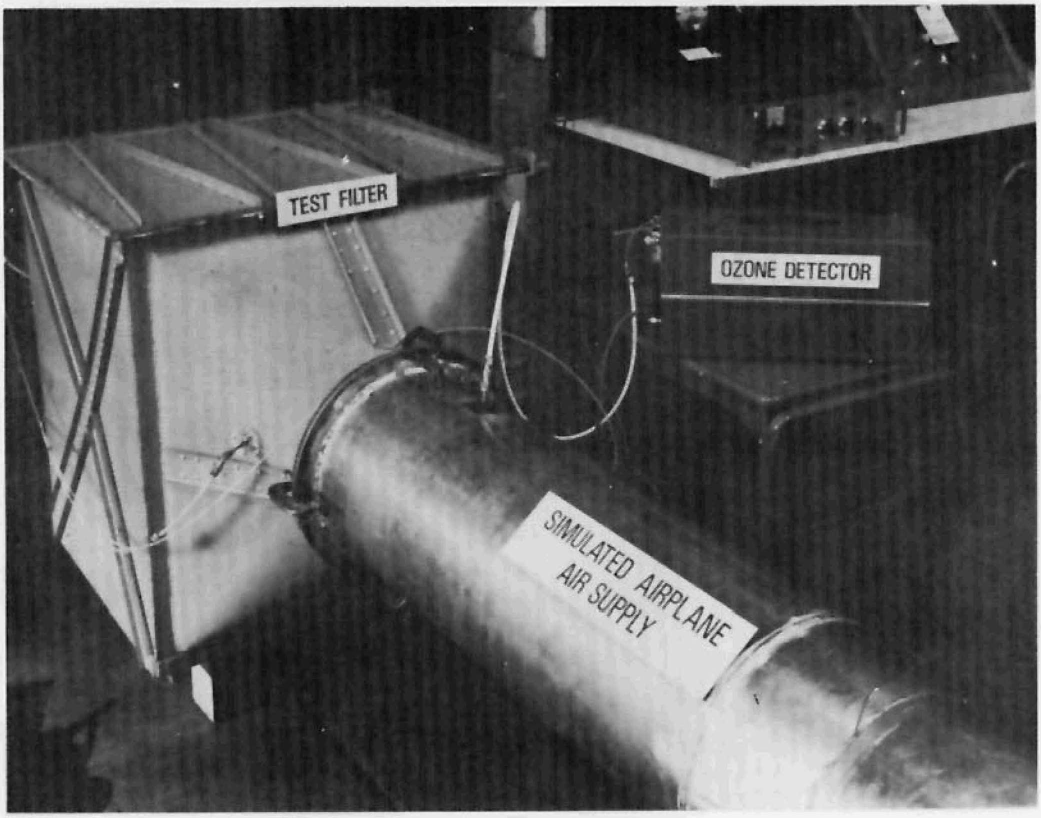


FIG. 10. CABIN ADSORPTION FILTER MATERIALS

TESTED

- CHARCOAL
  - BARNEBY CHENEY TYPE AC
  - * BARNEBY CHENEY TYPE 848
  - WHITCO 955
  - NORTH AMERICAN G 210
  - NORTH AMERICAN G 212
  - UNION CARBIDE JXC
  - WESTAVACO NUCHAR
- HOPCALITE & HOPCALITE/ CLOTH
- AMBERSORB
- ZEOLITES 4A, 5A, 7/8 13X
- SILVASAN (PURALOTOR)
- ULTRA-VIOLET
- MSA HOPCALITE FILTER PANEL
- ENGELHARD CATALYST P/N A-18673

* Presently In Use

FIG. 11. SMALL SCALE LAB TEST RESULTS - CHARCOAL

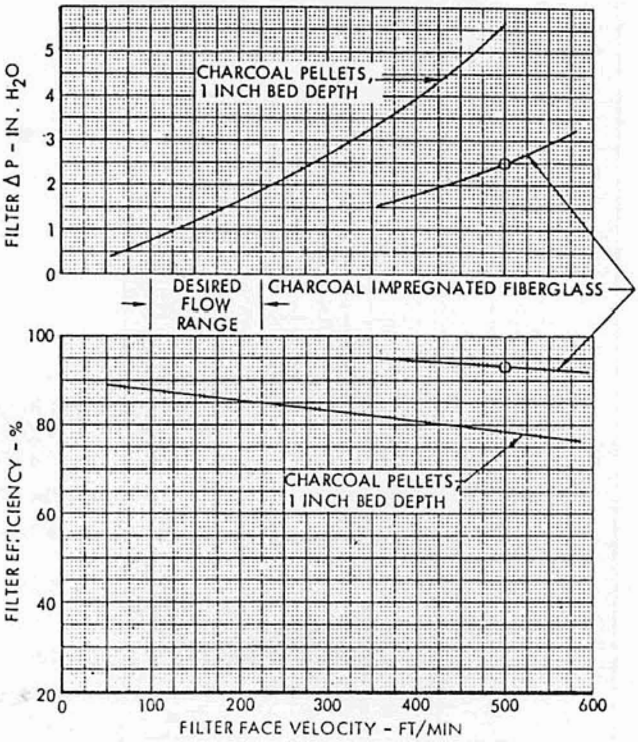


FIG. 12. FULL SCALE LAB TEST RESULTS - CHARCOAL FILTERS (ZONES 2 AND 3)

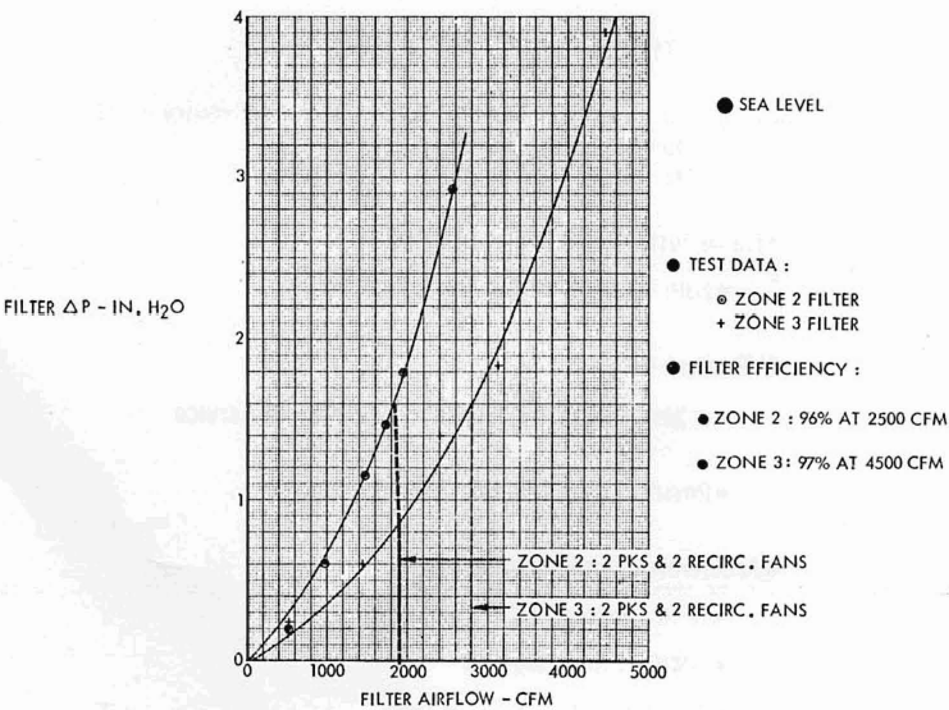


FIG. 13. FULL SCALE LAB TEST RESULTS - CHARCOAL FILTERS (ZONES 1 AND 4)

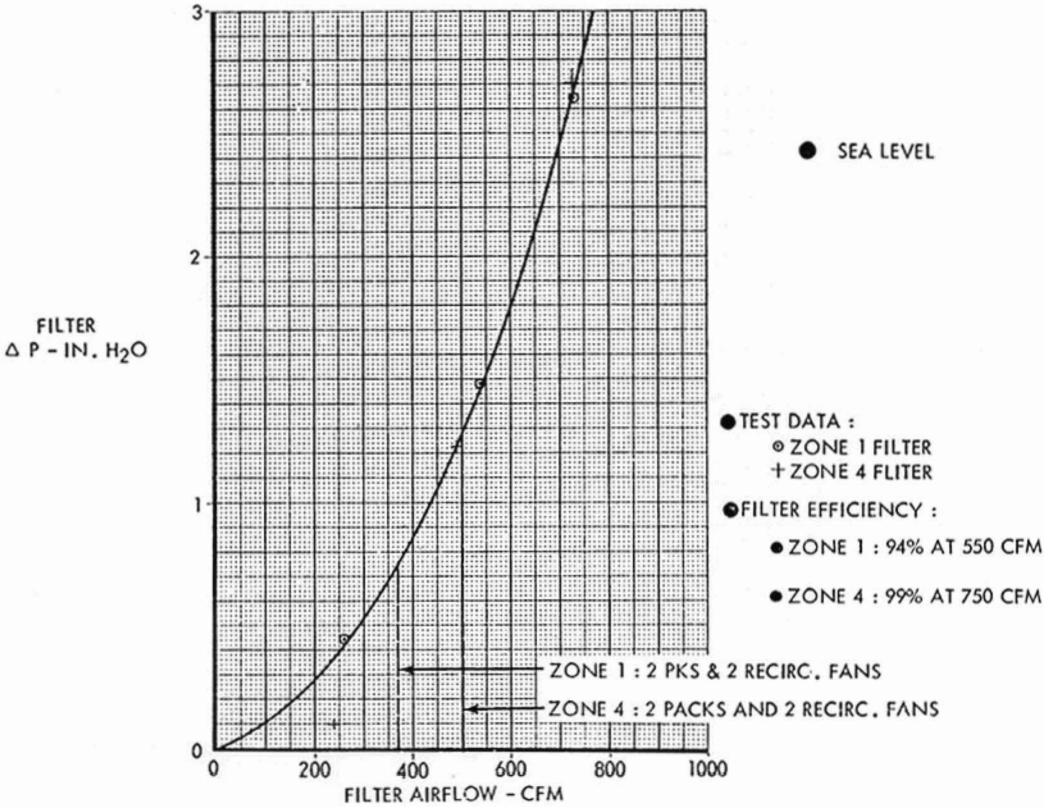
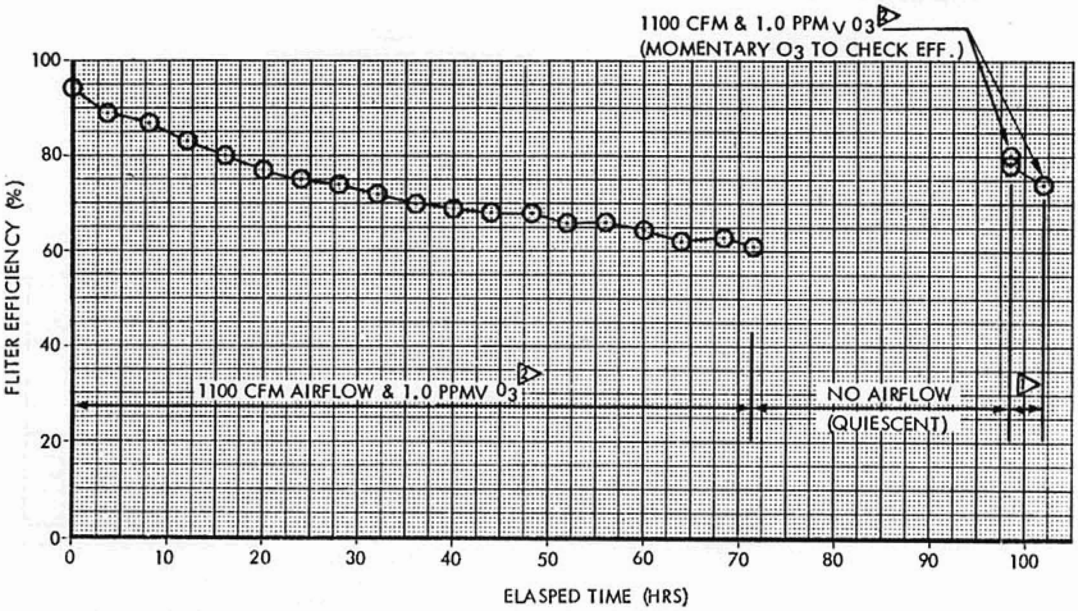


FIG. 14. DESIGN VERIFICATION TESTS

Objective: To Show Compliance With Certification Requirements
To Give Confidence For Safety
To Indicate Effectivity Vs. Time Effect

- Flame Tests (Certification Requirement)
  - Both 12 Sec & 60 Sec Flame Test Passed
- Vibration Tests
  - 0.24% Wt Loss In Simulated One Year Of Service
  - Result - Much Better Than Anticipated
- Accelerated Contamination Tests
  - 72 Hr. Ozone Test
  - JP4/O_3/Time/Temp Test
  - Simulated Service Cycle Test

FIG. 15. OZONE FILTER EFFECIENCY VS TIME - LAB TEST OF RA001 FILTER



1100 CFM AIR WITH NO OZONE

HIGH OZONE CONCENTRATION USED FOR LAB TEST TO ACCELERATE LIFE CYCLE TIME

FIG. 16. FULL SCALE LAB TEST RESULTS - RA001 FILTER CONTAMINATION CYCLE TEST - 1 INCH CHARCOAL BED

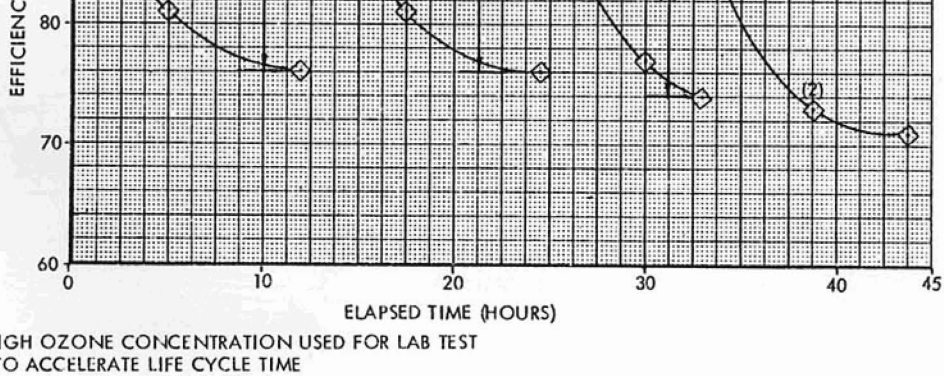
TEST CYCLE

(1) INJECT 10. CC OF JP-4

(2) OZONE INJECTED @ 1.0 PPM_V @ 2,200 CFM

(3) HOT AIR CLEAN AT 200°F

(4) NO HOT AIR CLEAN - 3 HR REST ONLY



HIGH OZONE CONCENTRATION USED FOR LAB TEST TO ACCELERATE LIFE CYCLE TIME

FIG. 17. ZONE 2 FILTER LIFE CYCLE TEST USING BARNEBY CHENEY TYPE A/C CHARCOAL

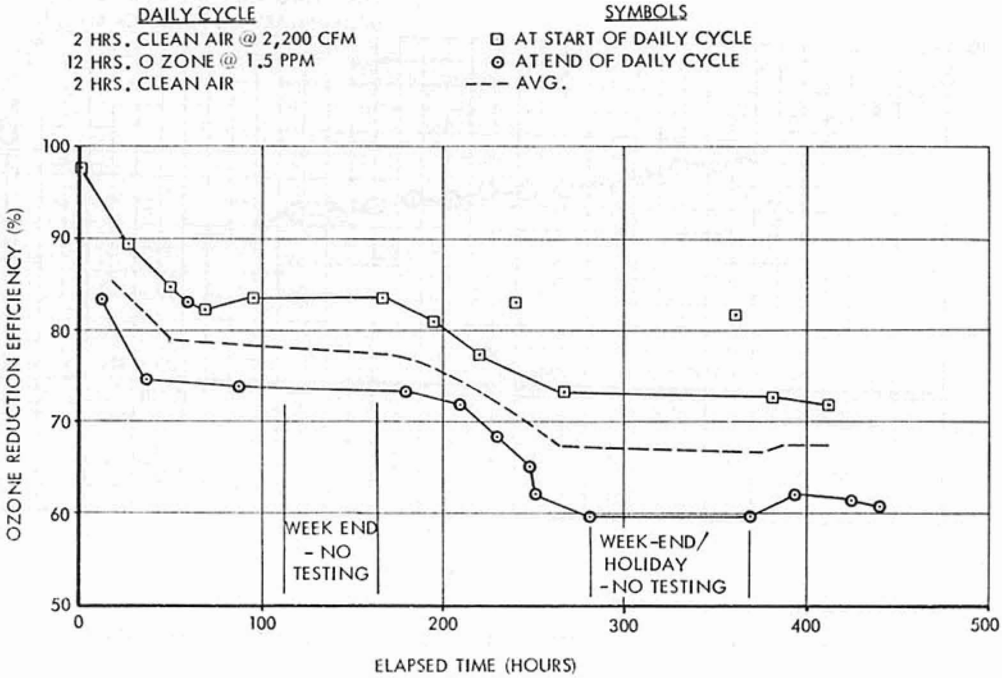


FIG. 18. CONDITIONED AIR FILTER INSTALLATION

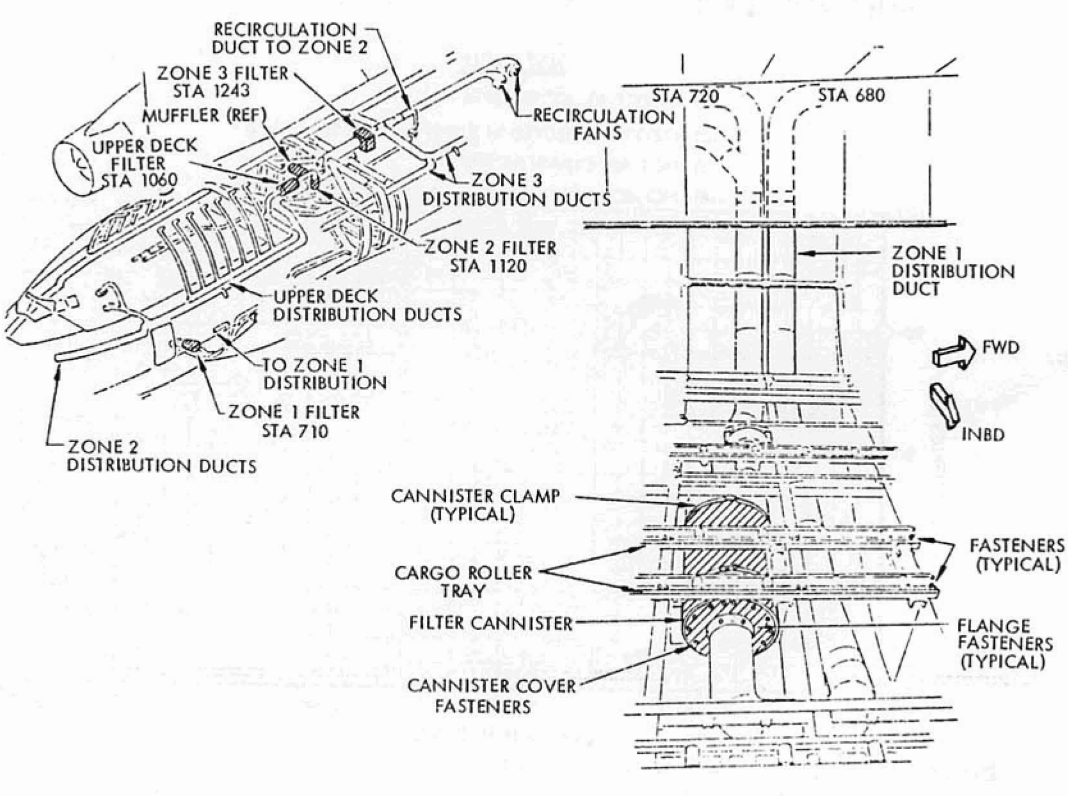


FIG. 19. CONDITIONED AIR FILTER INSTALLATION

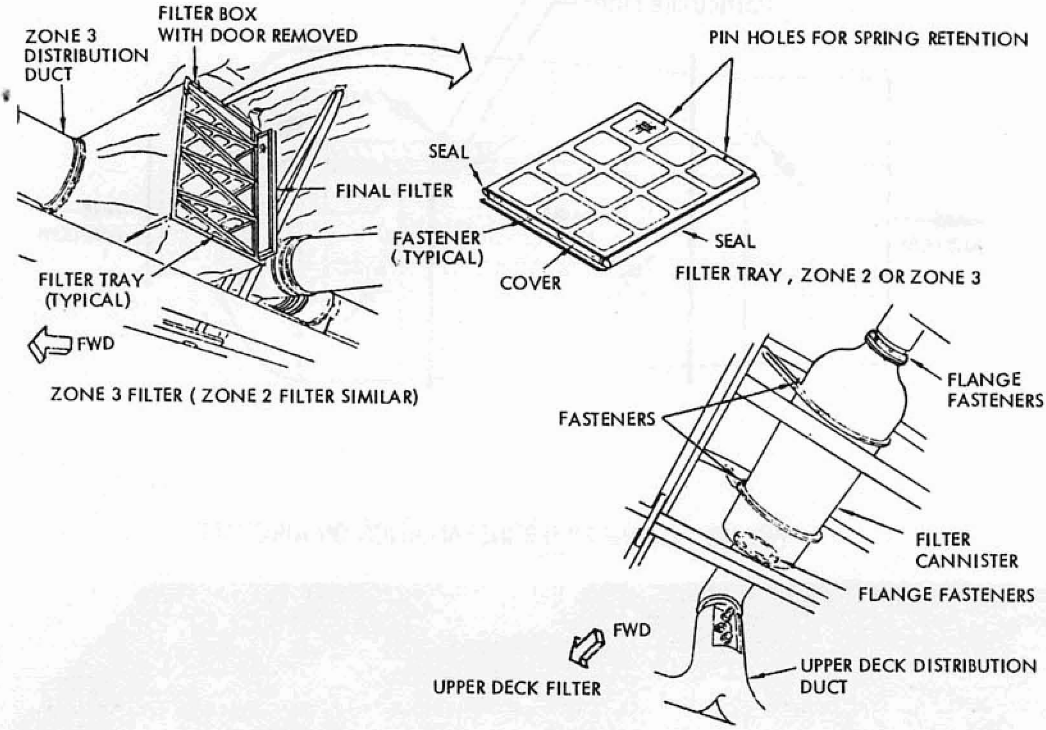


FIG. 20. OZONE FILTER

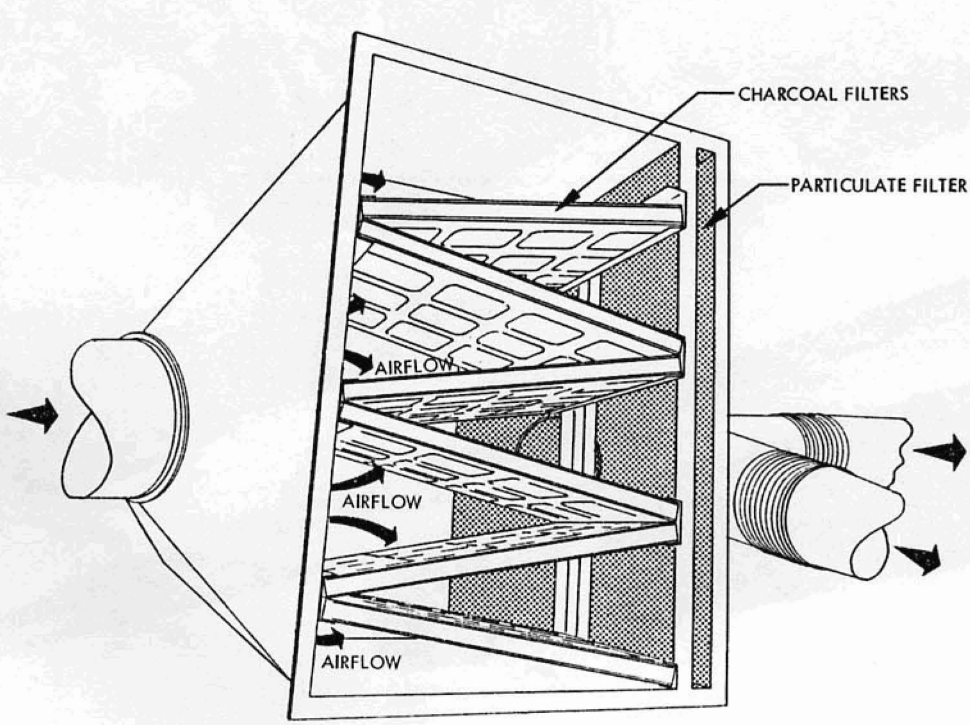


FIG. 21. CHARCOAL FILTER CANISTER TYPE - ZONES 1 AND 4

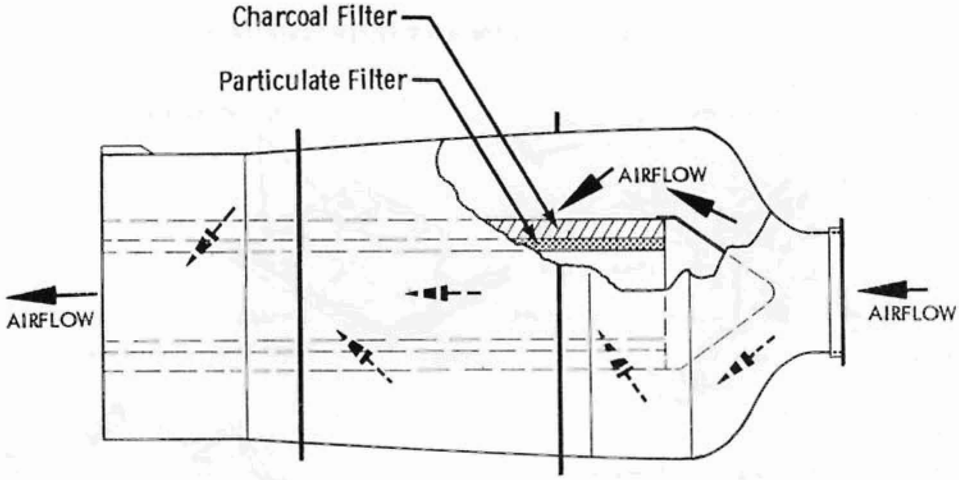


FIG. 22. OZONE FILTER INSTALLATION ON AIRCRAFT

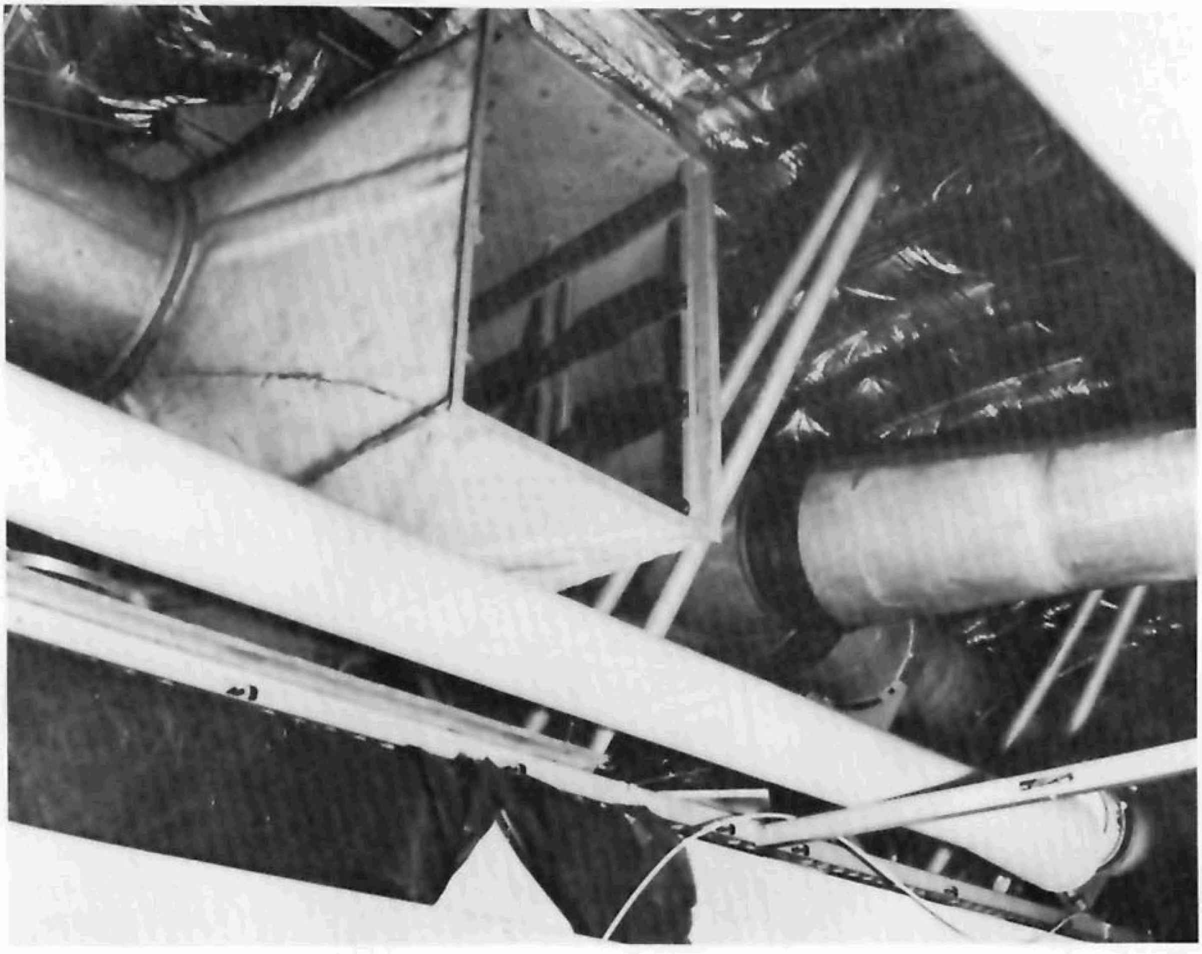
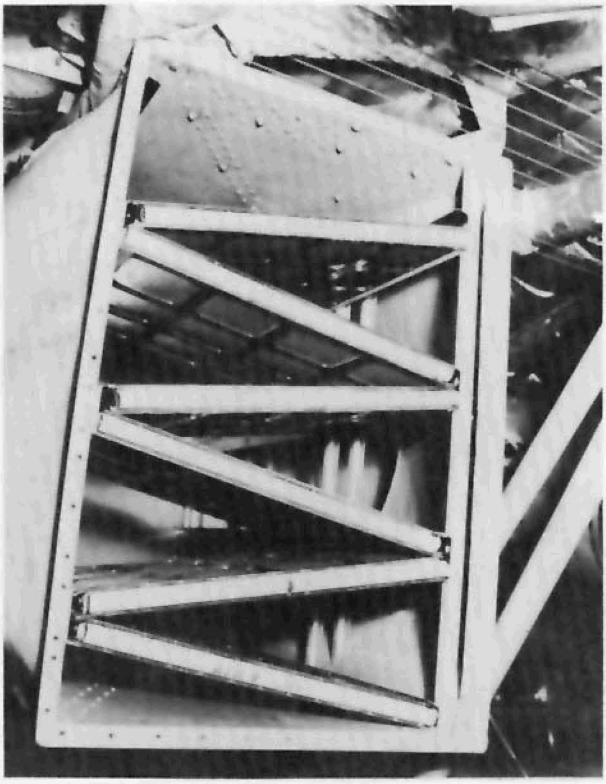


FIG. 22. CONTINUED.



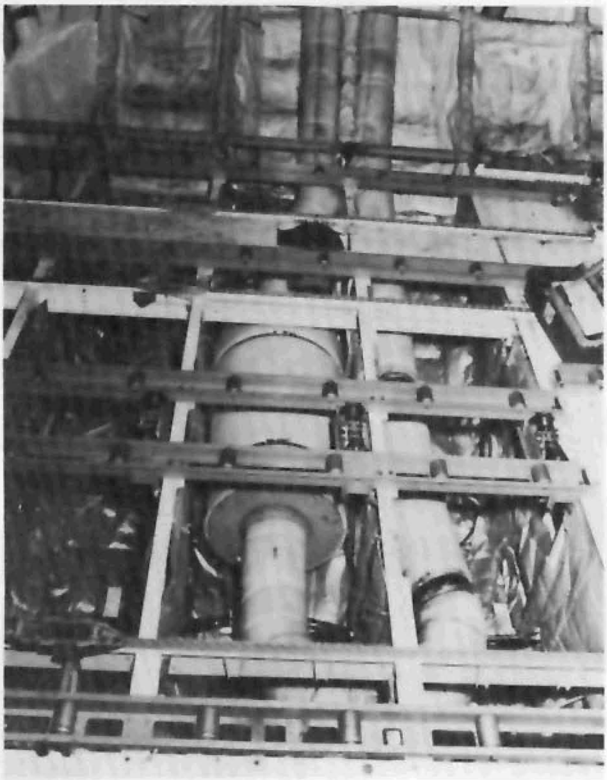


FIG. 22. CONCLUDED.

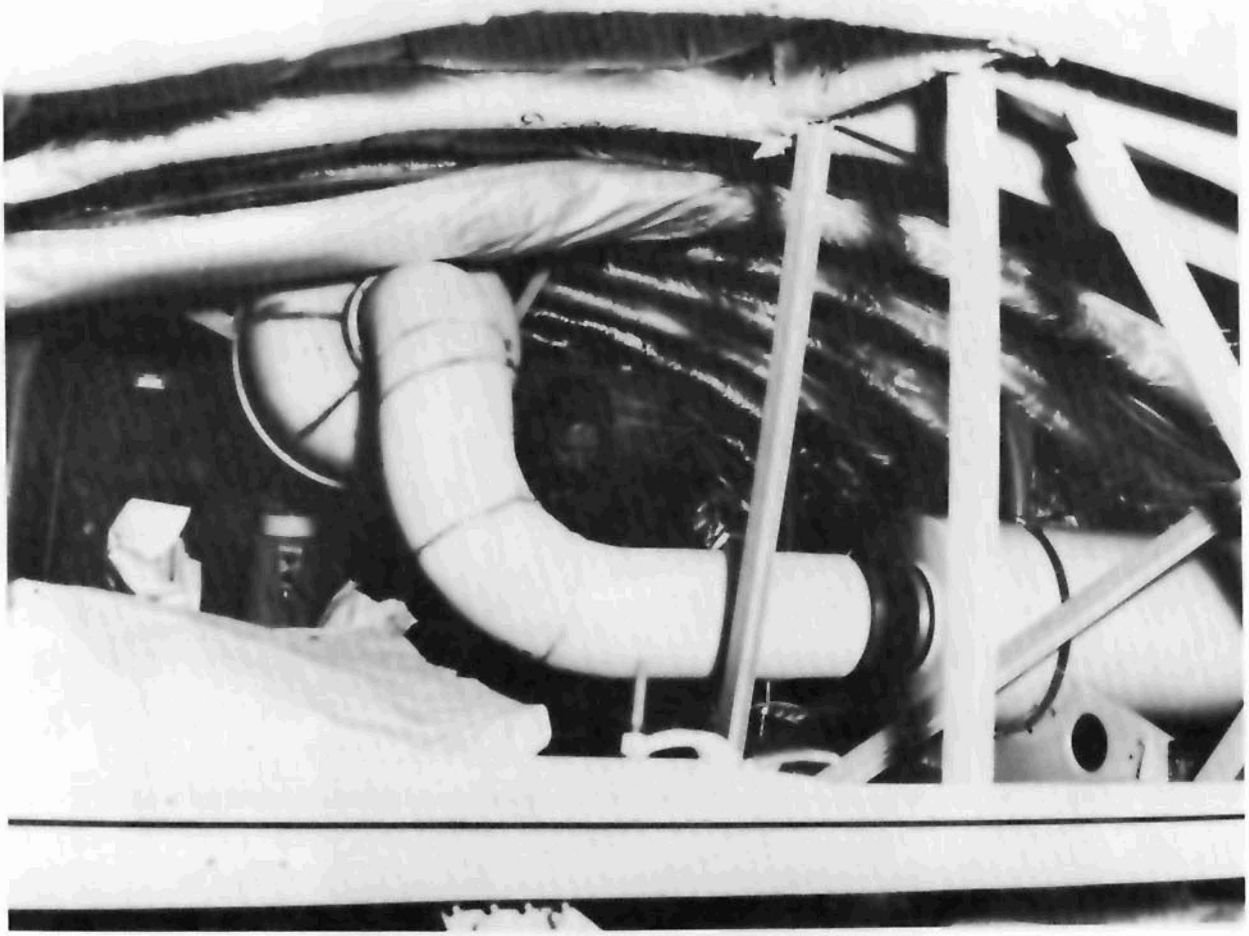


FIG. 23. ADDITIONAL CABIN FILTER LAB TESTS

- CHARCOAL SURVEY TESTS - SMALL SCALE
- PAA SERVICE FILTER LAB TESTS
- MSA PLEATED HOPCALITE MATERIAL
- ENGLEHARD CATALYST P/N A - 18673

FIG. 24. FILTER EFFICIENCY VS FILTER FACE VELOCITY - 1/2" CHARCOAL FILTERS

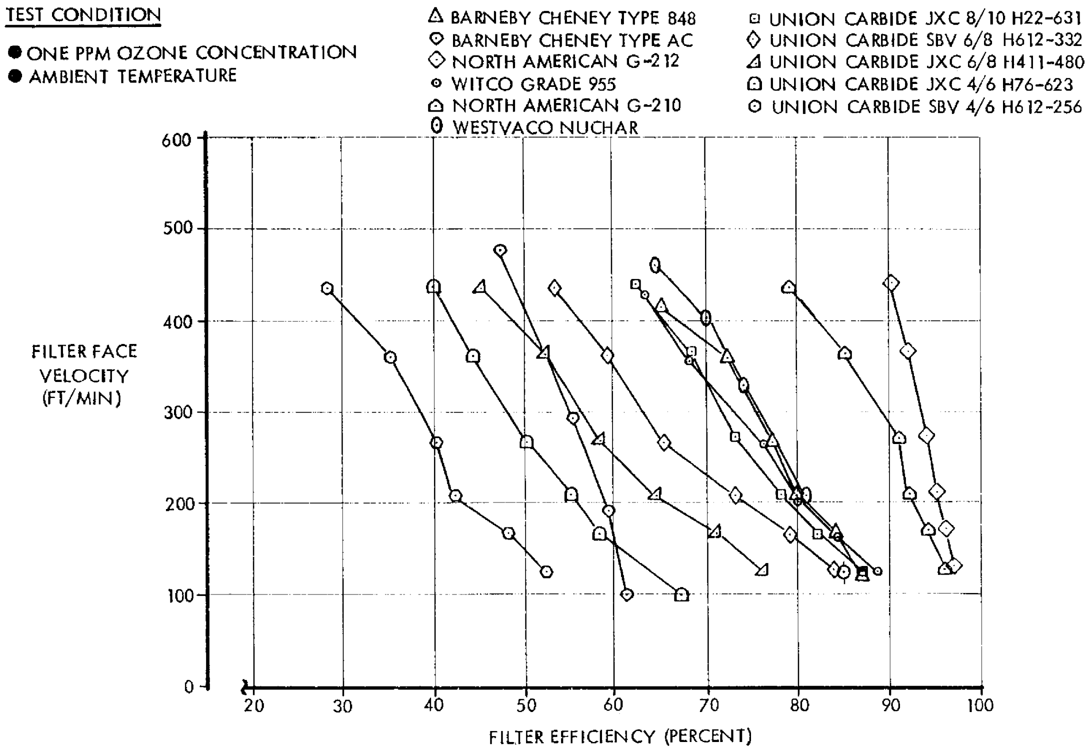


FIG. 25. PAA CHARCOAL FILTER EFFICIENCIES AS DETERMINED FROM LAB TEST DATA

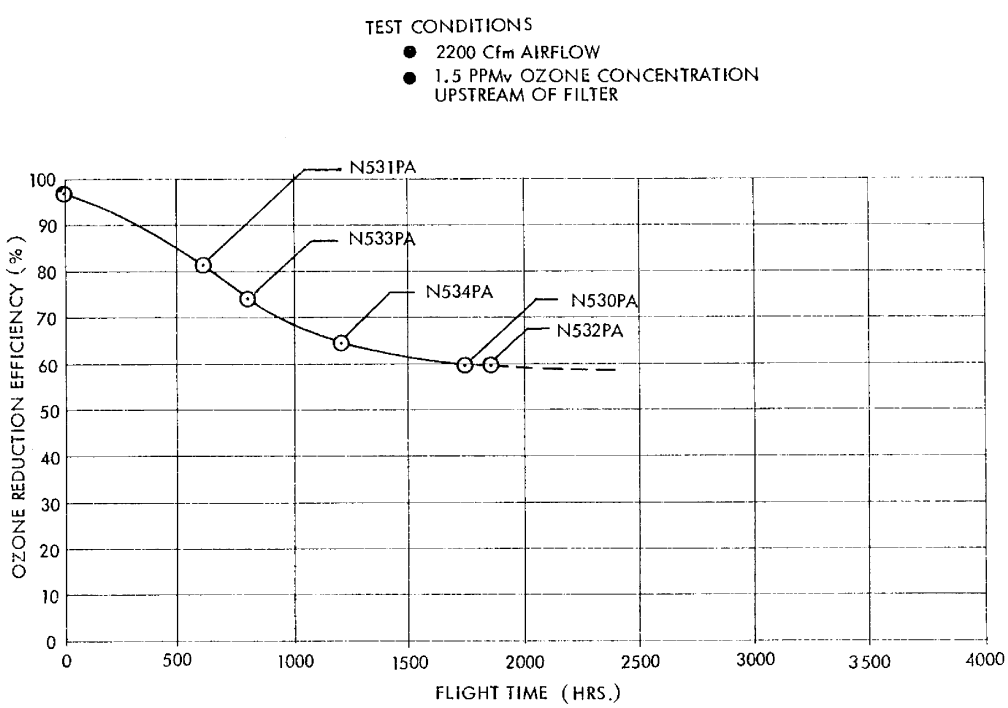


FIG. 26. MSA PLEATED HOPCALITE FILTER PANEL - LIFE CYCLE TESTING

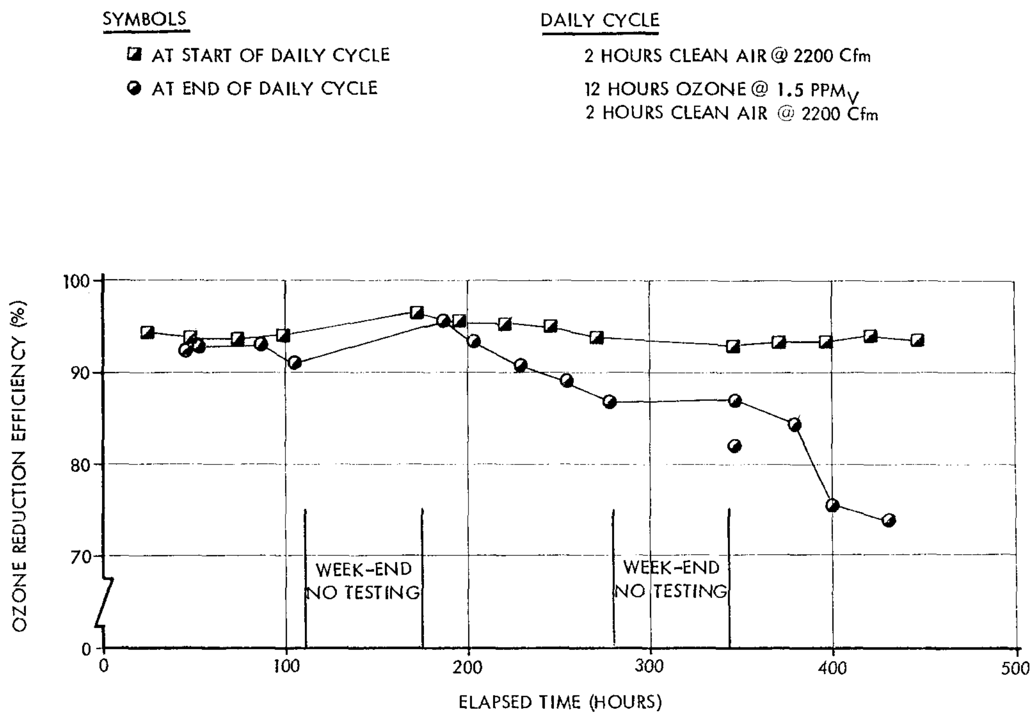


FIG. 27. MSA PLEATED HOPCALITE FILTER PANEL - FILTER EFFICIENCY VS. OZONE LEVEL

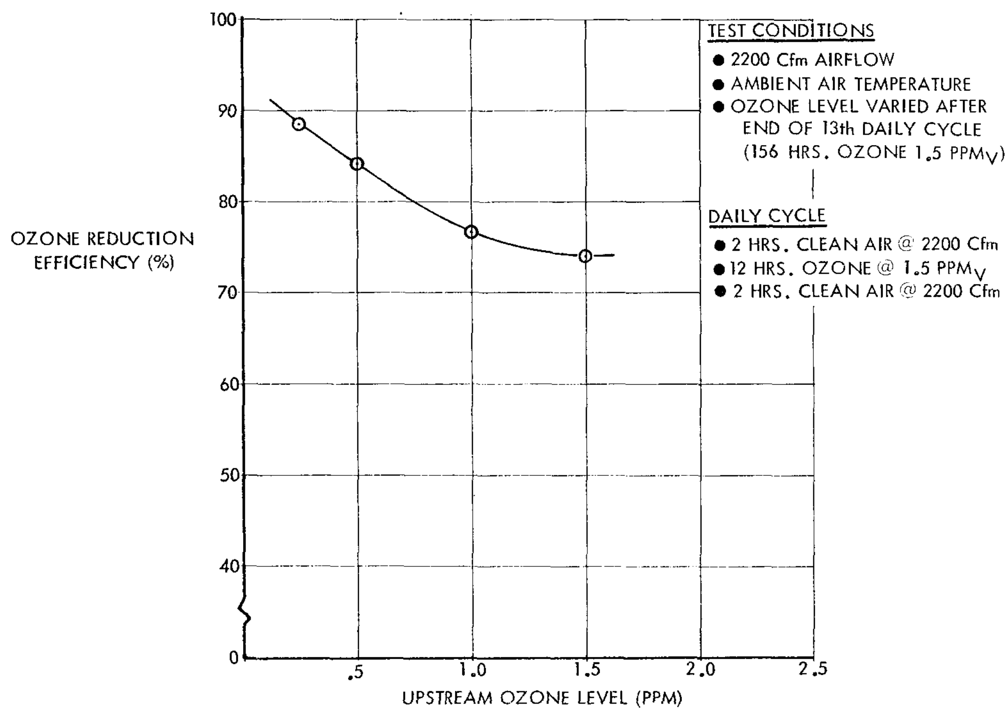


FIG. 28. FILTER EFFICIENCY VS FILTER FACE VELOCITY 1/2" THICK FILTERS

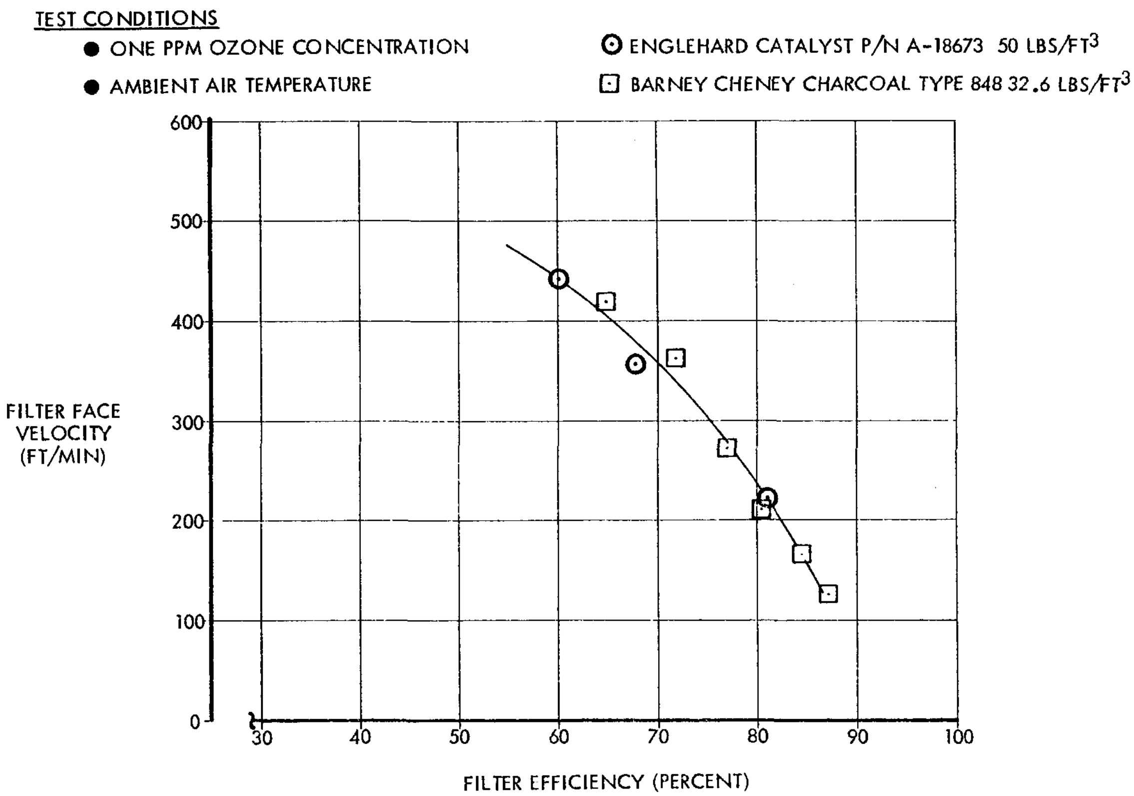


FIG. 29. PNEUMATIC DUCT (CATALYTIC MATERIALS)

TESTED

- MSA Hopcalite
- Nickel Screens
- Nickel Wool
- Brass Wool
- Zeolites 4A, 5A, & 13X
- Purolator Silvasan Cert 361
- United Oil Products Catalysts
  - No. 3443-120-25
  - No. P3-3008
  - Honeycomb Filter
- Alumina & Alumina/Silver Oxide
- Alumina/Cu 0
- Alumina/Mn 0_2
- Engelhard Catalyst
  - Spheres } DEOXO
  - Cylinders } DEOXO
  - Pellets P/N A-18673
  - Raremetal On Tubes And Ceramic Honeycomb
- 3M Company Honeycomb Filter
- Palladium (Rare Metal) Spheres
- Emery Ceramic Honeycomb Filter
- Dart Ind. Sintered Metal Filter

FIG. 30. PNEUMATIC MANIFOLD CATALYTIC FILTER LOCATIONS

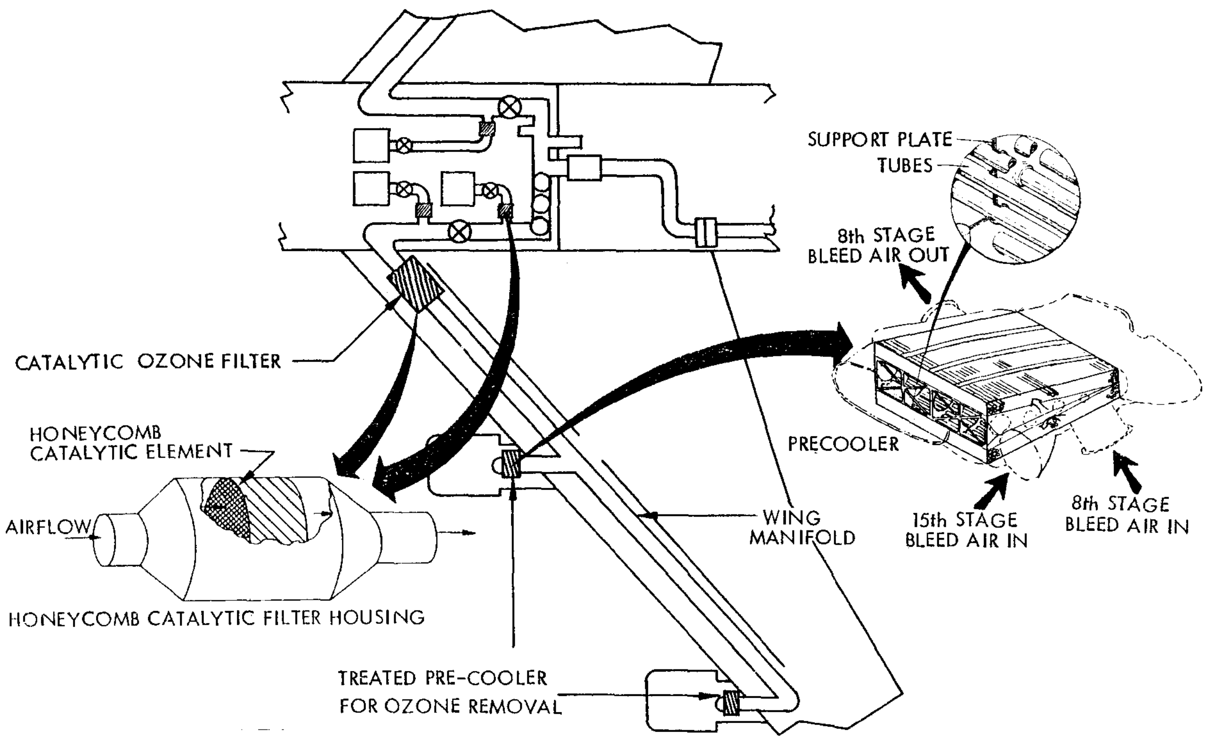
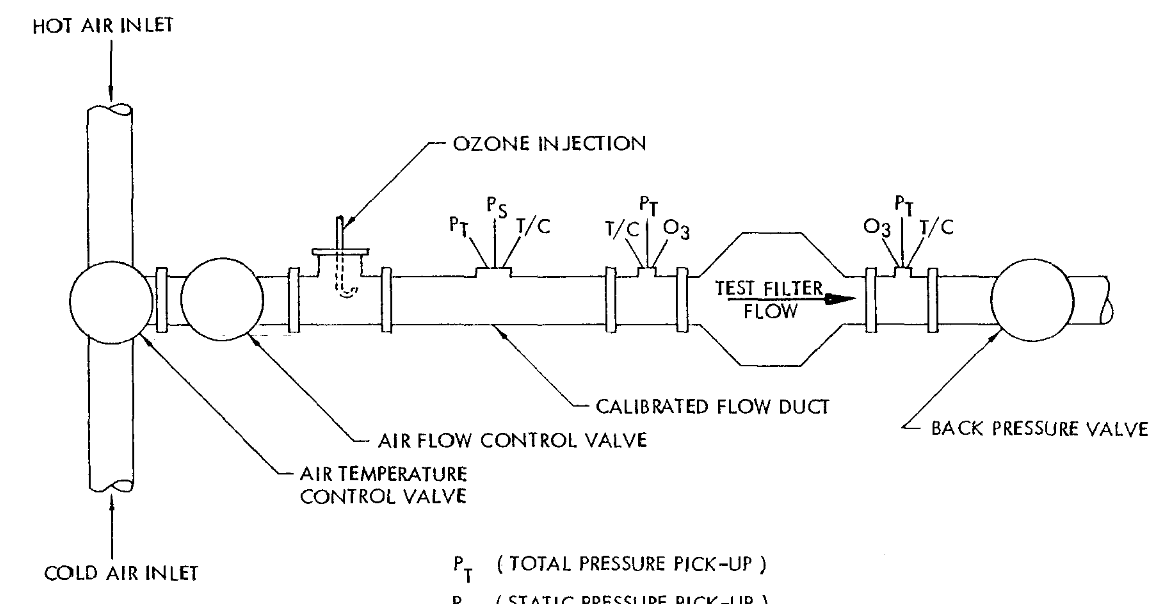


FIG. 31. FULL SCALE PNEUMATIC DUCT FILTER LAB TEST - TEST SETUP SCHEMATIC



P_T (TOTAL PRESSURE PICK-UP)

P_S (STATIC PRESSURE PICK-UP)

T/C (THERMOCOUPLE - AIR TEMPERTURE)

O_3 (OZONE SENSE LINE)

FIG. 32. FULL SCALE PNEUMATIC DUCT FILTER OZONE MEASUREMENTS SCHEMATIC

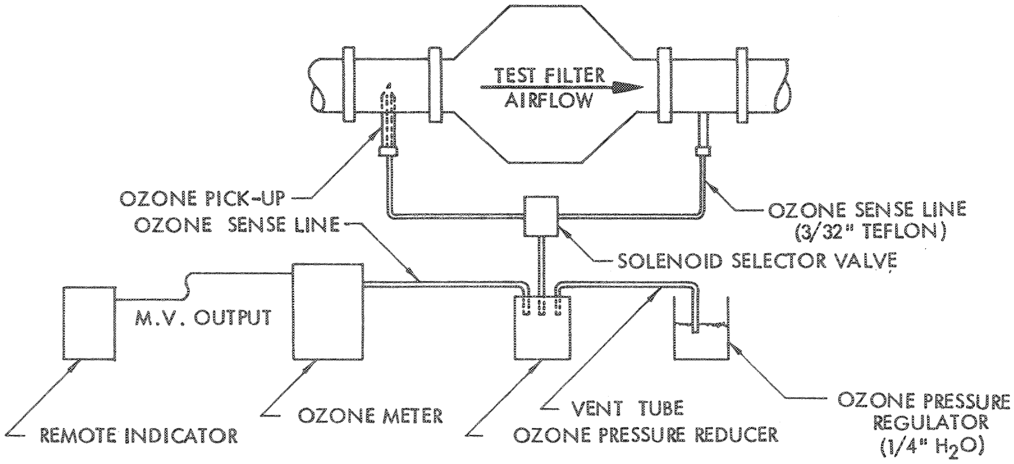


FIG. 33. PNEUMATIC DUCT FILTER - LAB TEST SETUP

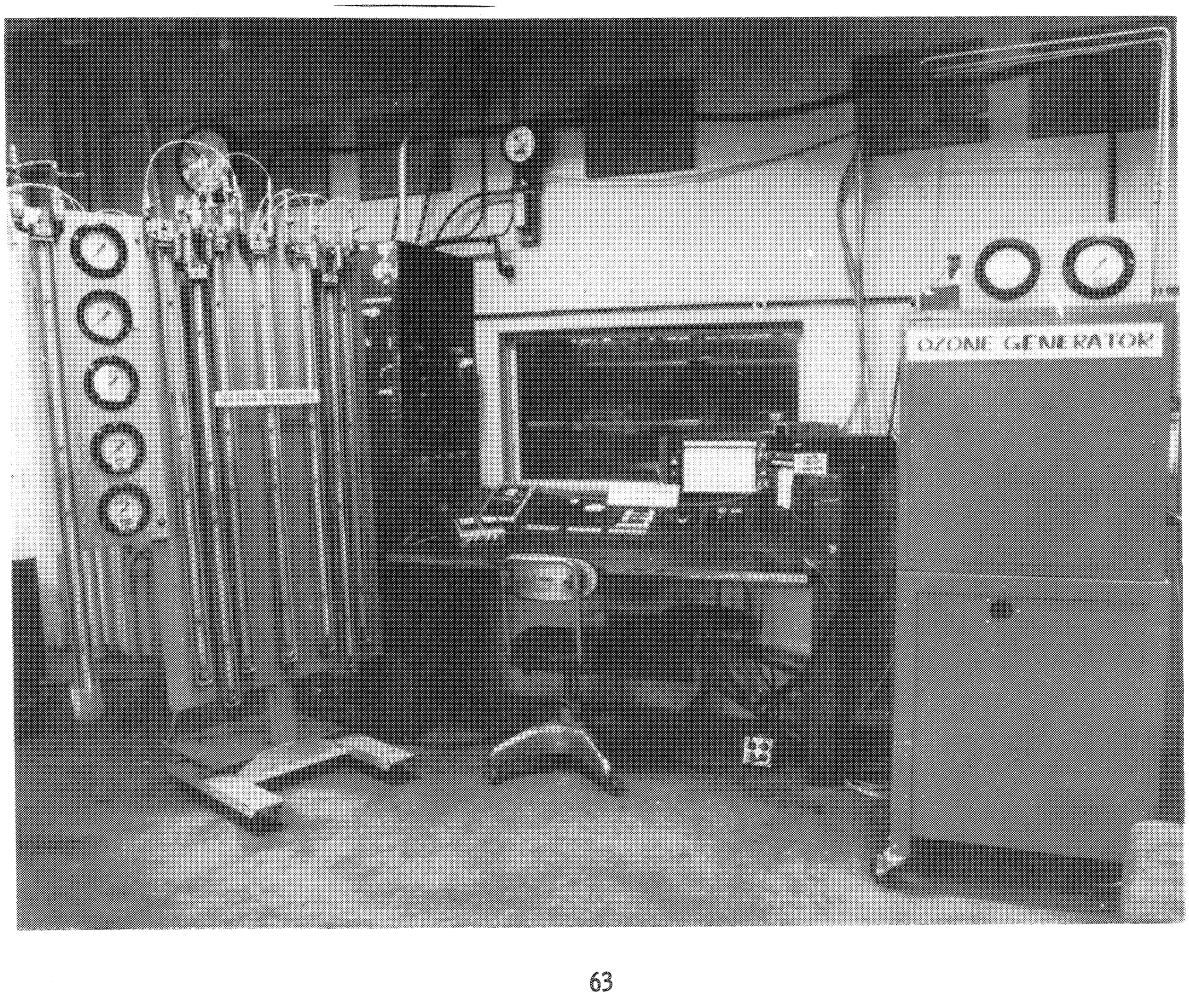
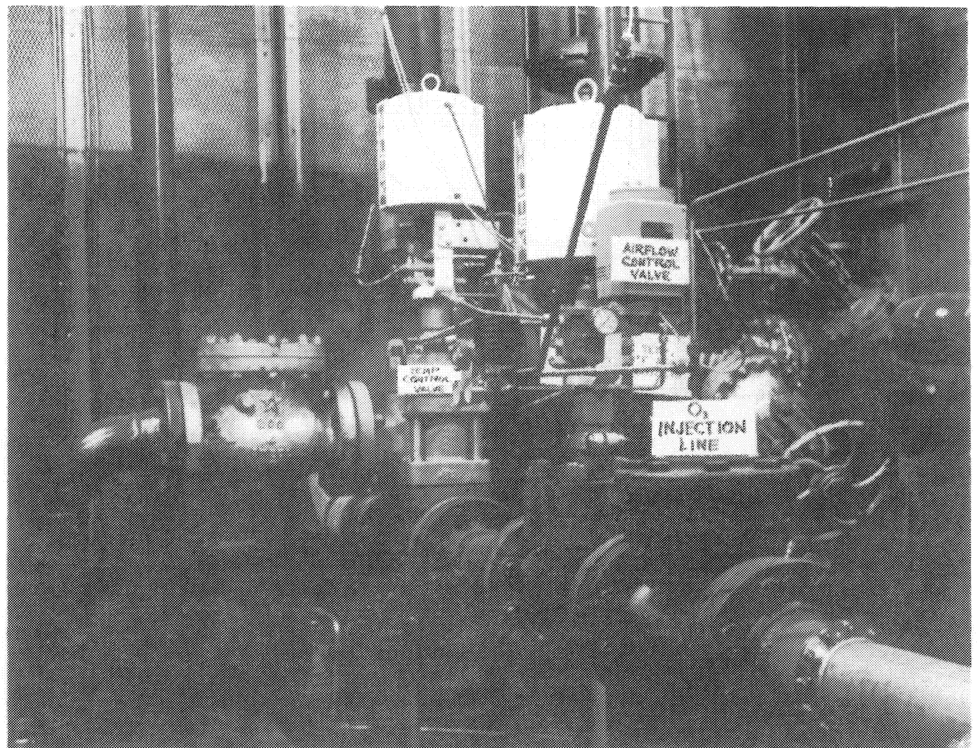


FIG. 33. CONCLUDED.



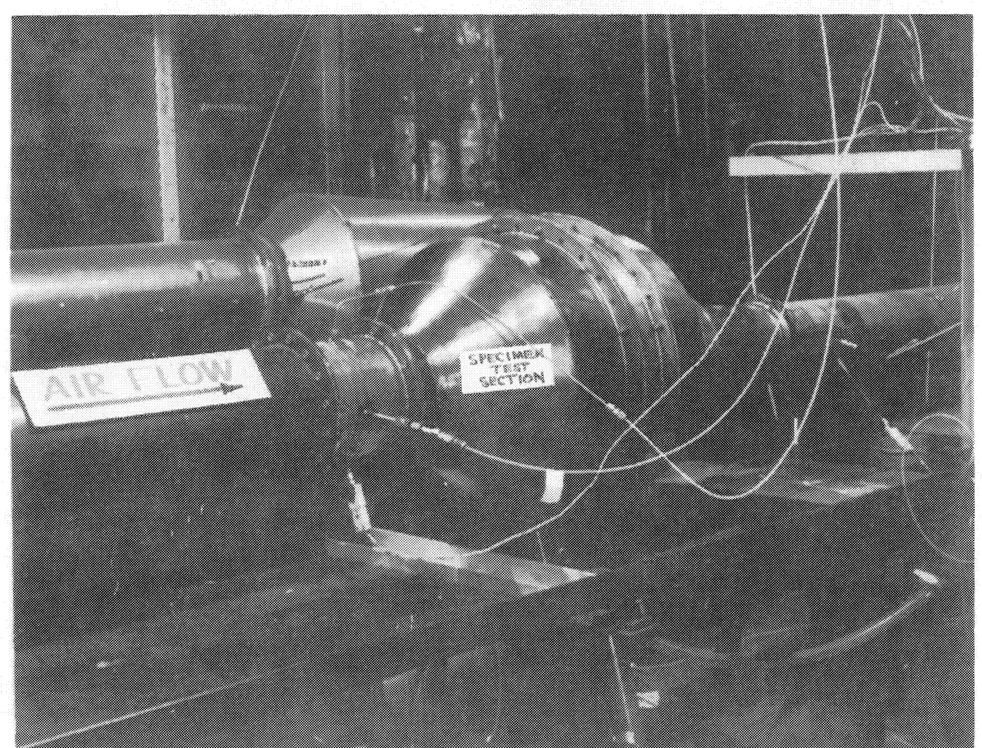


FIG. 34. OZONE MEASUREMENTS SETUP

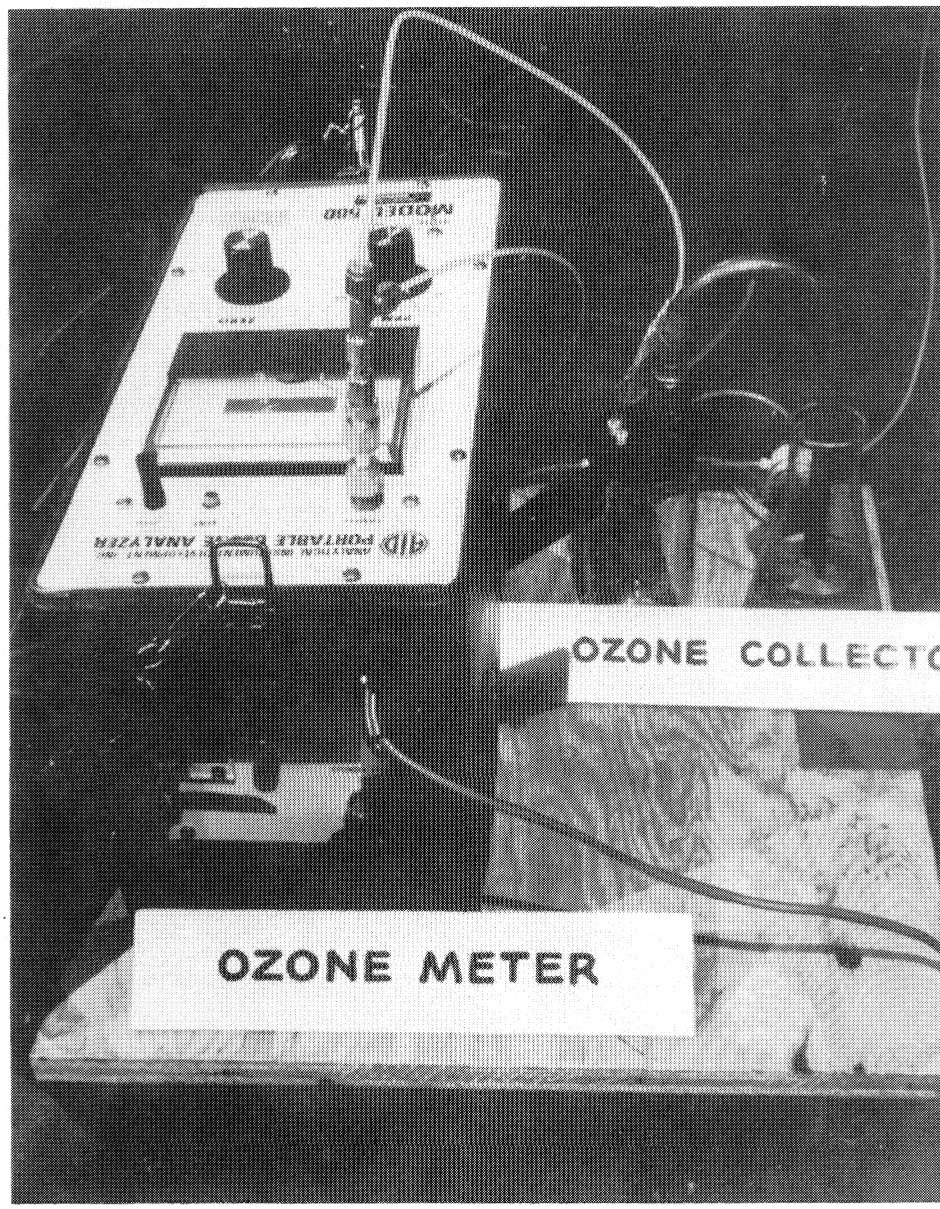


FIG. 35. LAB TEST RESULTS

- ENGLEHARD CATALYST
- HOPCALITE
- HONEYCOMB CATALYST
- DART SINTERED METAL

FIG. 36. ENGLEHARD CATALYST PIN A-1867 FILTER PERFORMANCE - SMALL SCALE TEST RESULTS

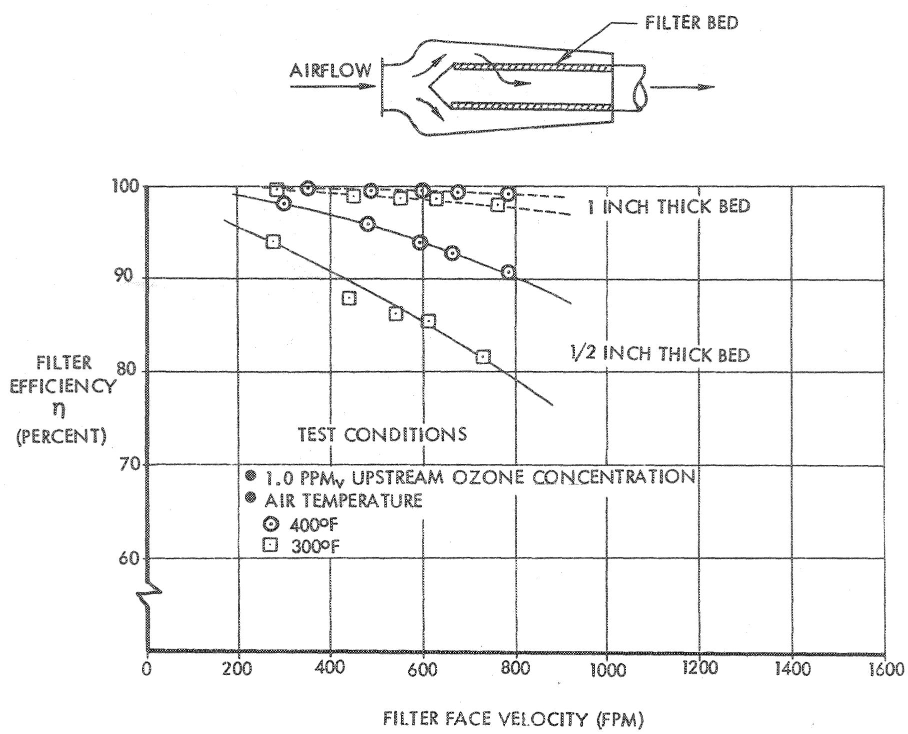


FIG. 37. HOPCALITE OZONE FILTER PERFORMANCE - SMALL SCALE TEST RESULTS

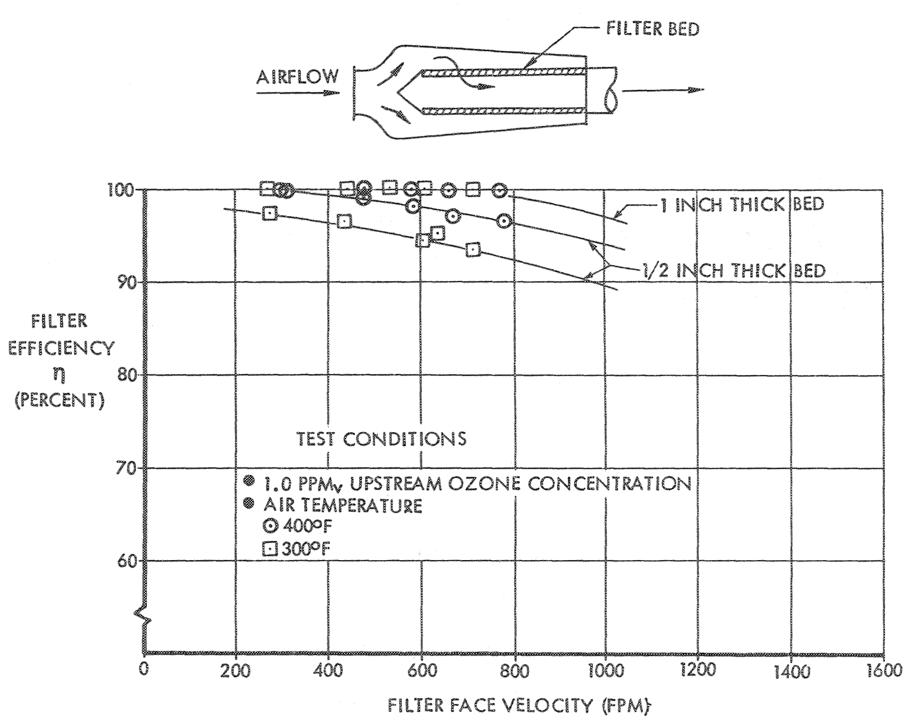


FIG. 38. HONEYCOMB CATALYTIC OZONE FILTER PERFORMANCE - FULL SCALE TEST RESULTS

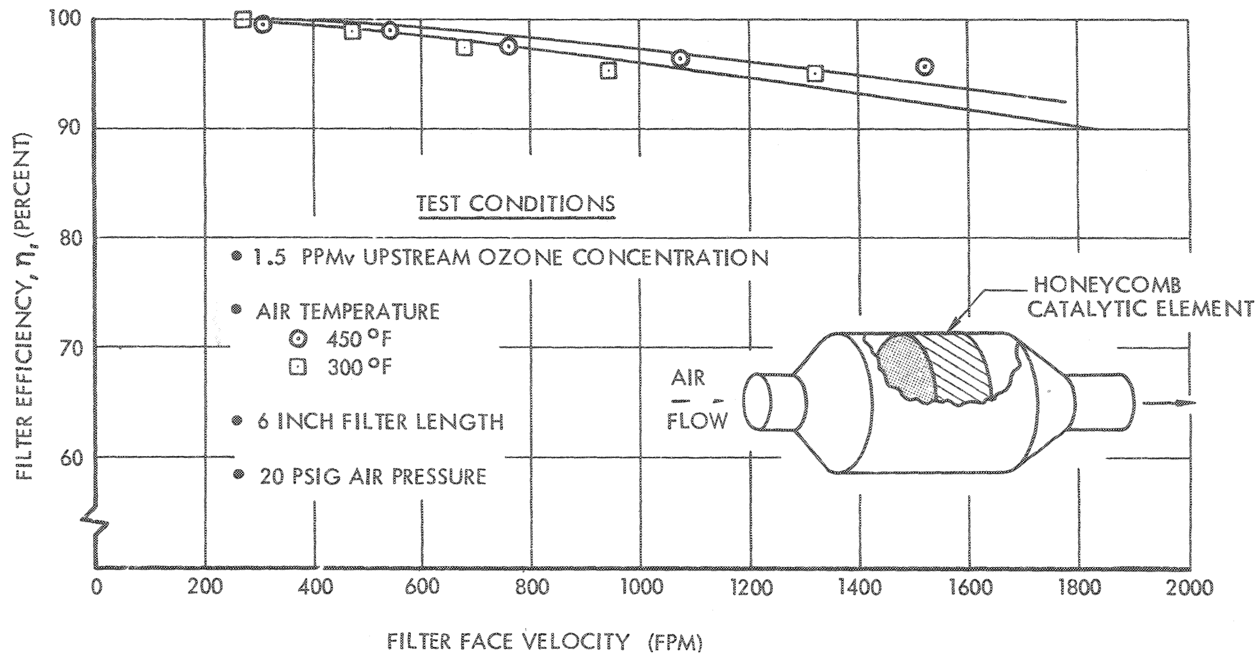


FIG. 39. DART SINTERED METAL OZONE FILTER PERFORMANCE - FULL SCALE TEST RESULTS

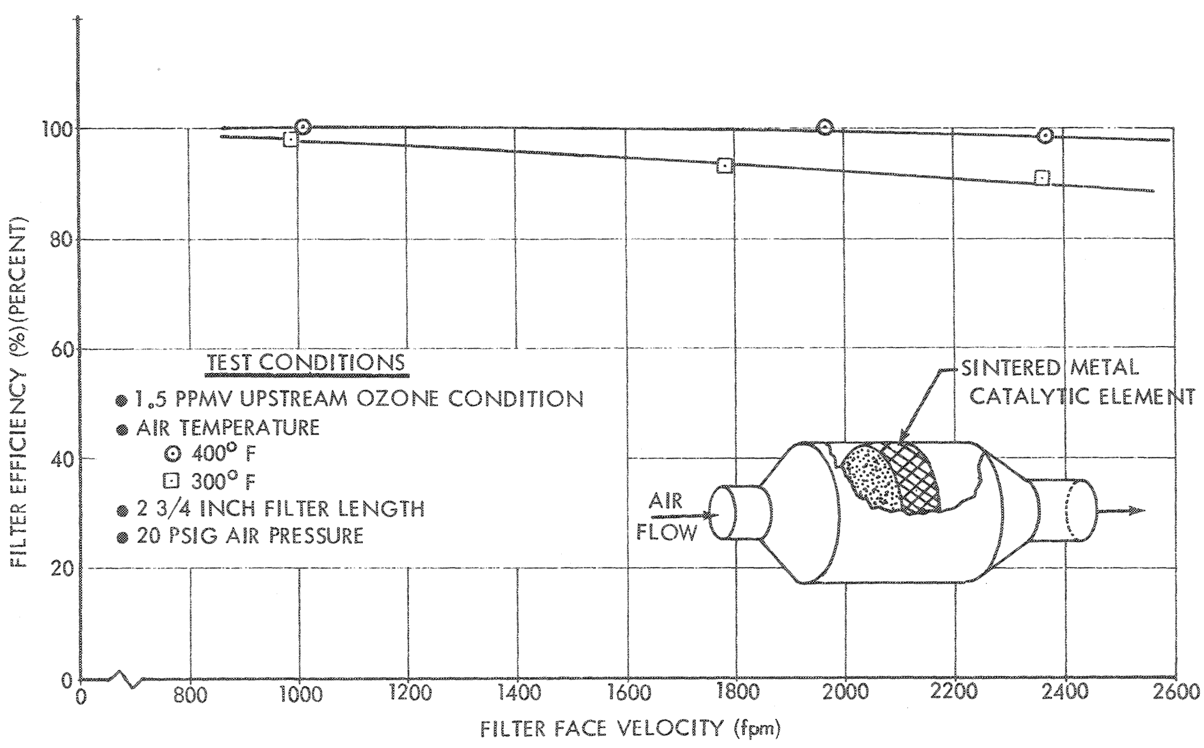


FIG. 40. HONEYCOMB CATALYTIC FILTER EFFICIENCY VS BED CONTACT TIME

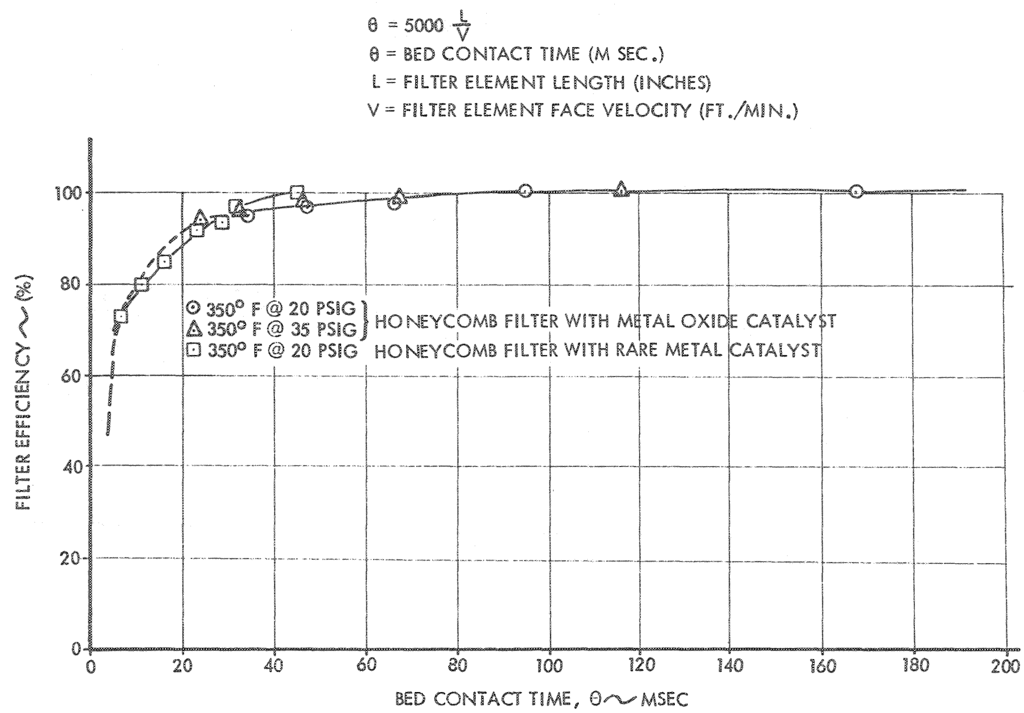


FIG. 41. EFFECT OF FUEL CONTAMINATION ON OZONE FILTER EFFICIENCY - RARE METAL HONEYCOMB FILTER UNIT

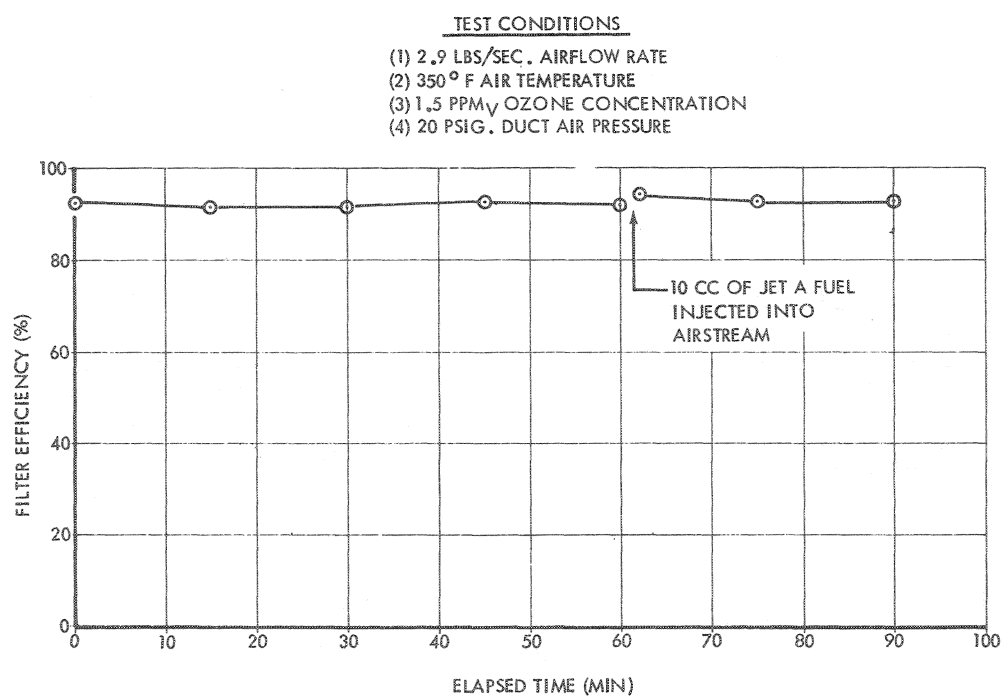


FIG. 42. RARE METAL HONEYCOMB OZONE FILTER LIFE CYCLE TEST

TEST CONDITIONS

(1) 2.9 LBS/SEC AIRFLOW
(2) 1.5 PPMv UPSTREAM OZONE LEVEL
(3) 300° F AIR TEMPERATURE

DAILY CYCLE

1 HR. CLEAN AIR @ 2.9 LBS/SEC
14 HRS. OZONE @ 1.5 PPMv & 2.9 LBS/SEC. AIRFLOW
1 HR. CLEAN AIR @ 2.9 LBS/SEC.
8 HRS. NO AIRFLOW

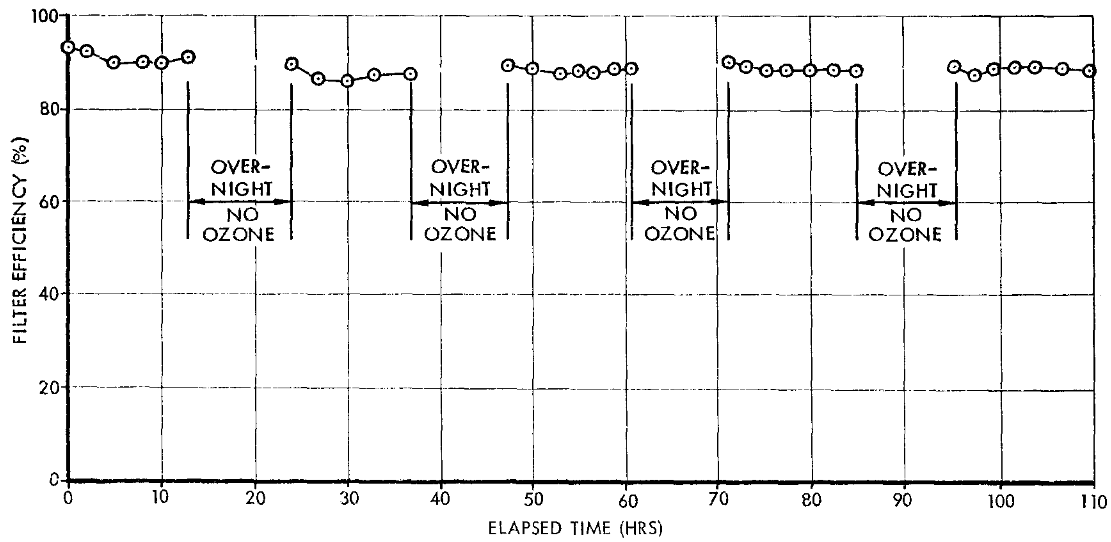


FIG. 43. METAL OXIDE HONEYCOMB OZONE FILTER LIFE CYCLE TEST

TEST CONDITIONS

(1) 3.71 LBS/SEC AIRFLOW
(2) 1.5 PPMV UPSTREAM OZONE LEVEL
(3) 300o F AIR TEMPERATURE

DAILY CYCLE

1 HR CLEAN AIR @ 3.71 LBS/SEC
14 HRS OZONE @ 1-5 PPMV & 3.71 LBS/SEC AIRFLOW
1 HR CLEAN AIR @ 3.71 LBS/SEC
8 HRS NO AIRFLOW

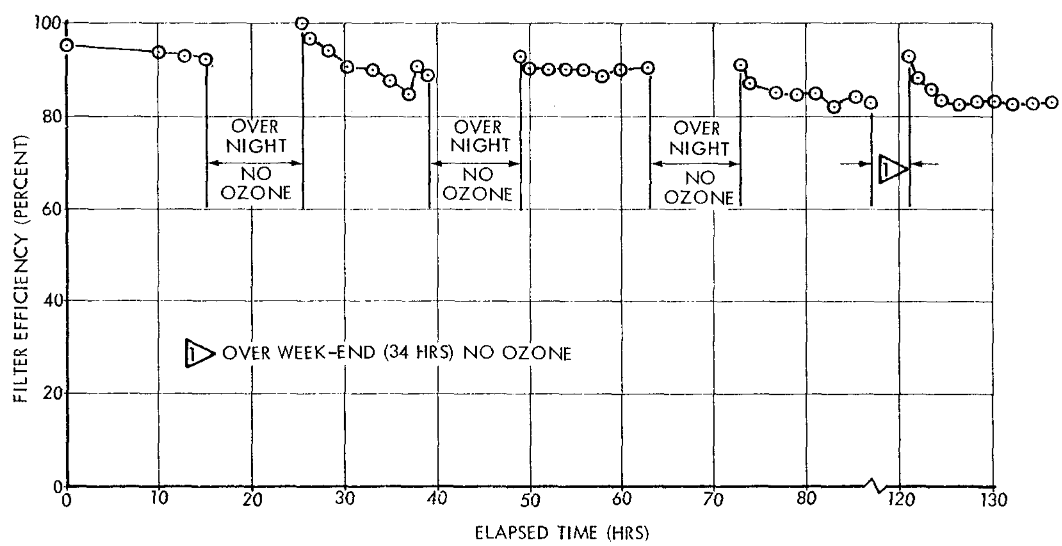


FIG. 44. EFFECT OF TIME & OZONE LEVEL ON METAL OXIDE TYPE FILTER CATALYST ELEMENT PERFORMANCE

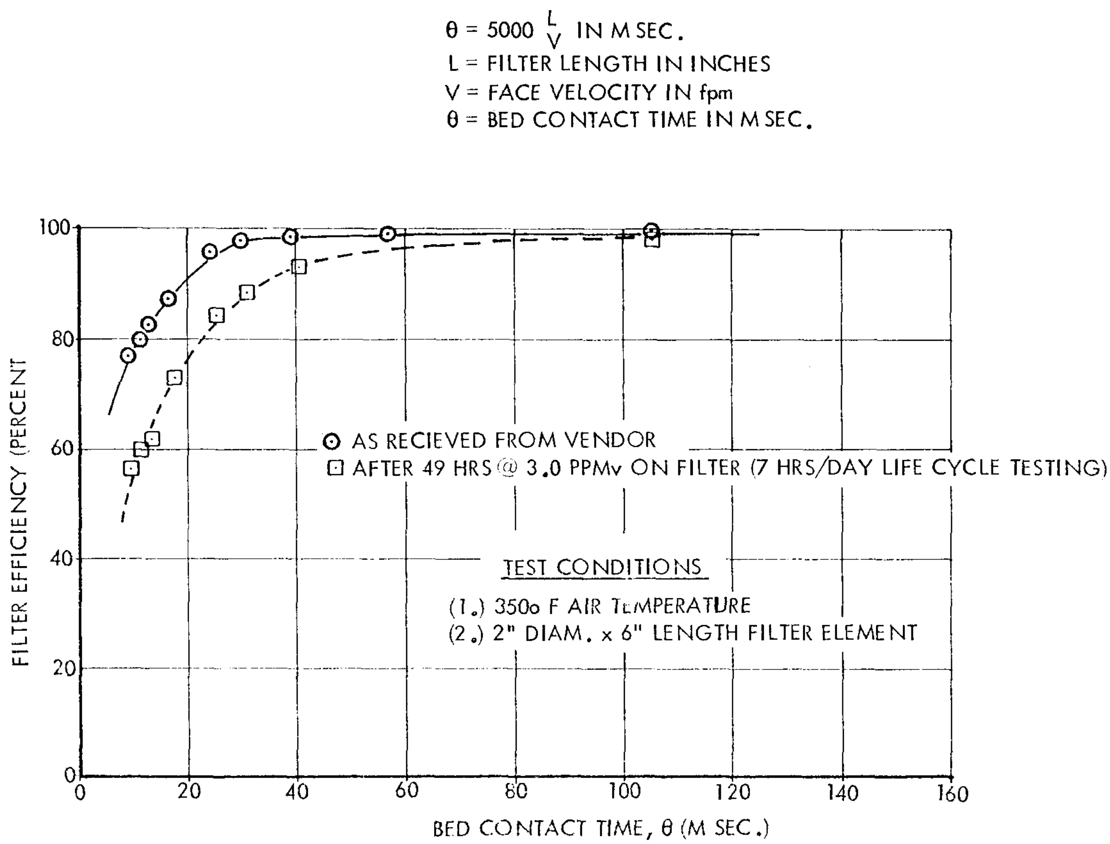


FIG. 45. FUTURE OZONE FILTER DEVELOPMENT PROGRAM

- MATERIAL TESTS
  - EVALUATE NEW MATERIALS
  - IMPROVE EFFICIENCY
  - REDUCE WEIGHT
  - ESTABLISH FILTER LIFE
- PRODUCTION FILTER
  - REQUEST PROPOSALS
  - PROCURE PROTOTYPE UNIT FOR LAB & SERVICE TESTS
  - FINAL PRODUCTION DESIGN & PROCUREMENT

APPENDIX C - PANEL MEMBERS AND ATTENDEES

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LLoyd Nygren, Boeing
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Carmen Azzopardi, IUFA
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		13. Type of Report and Period Covered Conference Publication
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A workshop on high ozone concentrations in the cabins of high altitude aircraft, sponsored by the NASA Office of Aeronautics and Space Technology, was hosted by the NASA Ames Research Center at Moffett Field, California on July 27-28, 1978. Participants represented airline and airframe companies, equipment manufacturers, university and company research organizations, cabin crews, and government agencies. Panels were organized to discuss in-flight ozone measurements, flight planning to avoid high ozone, and ozone destruction techniques. Major results and recommendations of these working groups included the requirement for additional ozone measurements on different types of aircraft, specific needs to improve ozone forecasting, and studies of materials used in ozone removal systems.

17. Key Words (Suggested by Author(s)) Airline operations; Flying personnel; Aircraft hazards; Toxic hazards; Aircraft compartments; Cabin atmosphere	18. Distribution Statement Unclassified - unlimited STAR Category 03

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